CHEMICAL AND PHYSICAL
LABORATORIES.

THE

# PLANNING AND FITTING-UP OF CHEMICAL AND PHYSICAL LABORATORIES.

WITH NOTES ON THE VENTILATION, WARMING AND LIGHTING OF SCHOOLS

BY

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WITH 36 ILLUSTRATIONS, COMPRISING PLANS OF LABORATORIES, WORKING DRAWINGS, SKETCHES AND DIAGRAMS OF FITTINGS AND OTHER DETAILS.

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# PREFACE.

COMPARATIVELY little has been published in this country respecting the planning and fitting-up of chemical laboratories. This fact was brought very forcibly to the author's notice a few years ago. He was then engaged in working out the details of the fittings for the chemical department at the Manchester Municipal Technical School, in accordance with the instructions of Dr. Thorpe, C.B., F.R.S., the Principal of the Government Laboratory.

As this lack of information applies also to physical laboratories, the author ventures to think some notes on these subjects may be of use.

The fitting-up of laboratories has considerably advanced since the issue of the late Mr. Robins's monumental work on "Technical School and College Building" (1887), copies of which are both scarce and expensive; the fittings are dealt with here in greater detail, although the limits of a small and handy volume have not been exceeded.

Books on chemistry very rarely refer, even in the briefest manner, to the arrangement of the laboratory. Three exceptions, however, may be mentioned: Professor Clowes's "Treatise on Practical Chemistry" (1899); Professor Worthington's "First Course of Physical Laboratory Practice" (1896); and the American work, by Messrs. Smith & Hall, on "The Teaching of Chemistry and Physics in the Secondary School" (1902).

The information given in the works on "Chemical Manipulation," by Faraday (1842) and by Greville Williams (1857), is now of more historical interest than practical utility.

My friend, Mr. Felix Clay, has just written a large and important treatise on "Elementary and Secondary School Buildings," and the greater part of one chapter deals with the teaching of chemistry and physics in the secondary school.

Descriptions of existing laboratories and their fittings appear from time to time in the various building and scientific periodicals, such as *The Builder*, *Nature*, *Chemical News*, *School World*, *Record of Technical Education*, etc.

In the following pages, what are considered to be the essential fittings in both large and small chemical and physical laboratories are described, so as to be applicable to all ordinary circumstances, but more especially to small school laboratories.

Concise and comprehensive descriptions, free from all technical expressions, have been aimed at.

In a book which endeavours to describe, in a practical and complete manner, fittings for every kind of chemical and physical laboratory, the description of the somewhat elaborate arrangements required for advanced work in large laboratories tends to create the false impression that all fittings are necessarily expensive and complicated.

The character of the fittings ought to be governed entirely by the nature of the instruction given, the size of the classes and the funds at command. As to their cost, it would be both misleading and useless to give any prices, as the varying requirements demand great diversity in size, design and even material, while the cost of labour is different in town and country.

No explanation is deemed necessary for devoting considerable space to such important subjects as Ventilation and Warming, the general principles and methods of which are set forth, with special reference to school buildings.

When writing these notes, the author has fully realised the great difficulty of giving any information of practical value that will be applicable under all conditions, as the requirements are never the same in any two laboratories.

He would like to take this opportunity of acknowledging his indebtedness to all the professors and teachers of chemistry and physics who have invariably, not only taken him round their laboratories and drawn his attention to every point of interest, but have so freely given him the benefit of their practical experience in all matters relating to the teaching of these sciences.

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*July*, 1903.

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THESE Illustrations are only intended to show the various types of fittings, etc., usually adopted; all important dimensions are figured, but the sizes given are, as indicated in the text, not necessarily unalterable.

# INTRODUCTION.

**Technical Education** has been, for several years, a subject of widespread interest. This fact, together with the increasing belief that a scientific training is a valuable part of a general education, is sufficient to account for the fact that almost every town in the United Kingdom has its technical institute, and almost every school and college its science laboratories.

Education, however, has recently made such rapid progress that many of these laboratories, through becoming inadequate for their requirements, have to be enlarged, remodelled, or superseded by entirely new buildings.

Therefore it may be concluded that the planning and furnishing of **Chemical and Physical Laboratories** is engaging the attention, from time to time, of many professors, committees, architects, and others, who may share with Dr. von Pebal the opinion "that no scientific institution requires the fulfilment of so many and such various conditions in its design and arrangement as a chemical laboratory," and that "the difficulties arising out of this increase considerably with the number of students for whom practical instruction must be provided."

**Practical Instruction in Chemistry and Physics is now acknowledged to be a necessary accompaniment to all theoretical or class instruction in these subjects.**

**This practical work requires suitable rooms and fittings.**

Although the value of the work carried on in school and college laboratories depends essentially on the teachers and the apparatus at their command, the important influence of surroundings is gradually being realised. In other words, well-planned, well-lighted, and well-ventilated laboratories exert an extremely beneficial effect on the students, encouraging them both morally and physically to do good work. Planning, lighting, and ventilation are, however, not everything; that these rooms should be maintained in a clean, neat and orderly condition is of almost equal importance.

**Chemical Laboratories** may be, broadly speaking, divided into three groups:—

(a) Those devoted to the teaching of chemistry.

(b) Those in which the work is chiefly of an analytical character, being either for the advancement of various trades and industries, or for the manifold applications of chemistry to the requirements of every-day life; and, lastly,

(c) Those established for research work in pure or applied chemistry.

These three groups naturally merge one into another, as, for example, advanced students in a college often carry on some original investigation.

The first group is, by far, the largest, as it includes the laboratories at schools, colleges and universities.

The second group embraces the laboratories of public analysts, and of analysts employed at steel, soap, chemical and other works.

As for the last group, there is, at present, in this country, only one laboratory, the Davy-Faraday, devoted solely to research work in pure science; research in applied chemistry, however, is carried on at many of the large manufactories and also at some colleges.

Well-equipped and properly-organised scientific laboratories were almost unknown until the middle of the last century.

In 1845 Lord Kelvin, then Mr. William Thomson, converted an old wine cellar in a house in Glasgow into a physical laboratory, and it served that purpose for several years.

The first laboratory for the teaching of chemistry was erected at the University of Giessen in Germany by Liebig, and opened in 1825. When the laboratory at Tübingen was afterwards built, the Giessen building was blindly copied in every detail, even to the omission of windows on one side of a large laboratory, although the reason for this omission at Giessen—the proximity of some adjoining buildings—did not occur at Tübingen.

Later, laboratories on an almost magnificent scale were built in Germany, Switzerland and Austria, as, for example, Hofmann's laboratories at Bonn and Berlin, and Than's at Buda-Pesth.

Of more recent years, chemical laboratories have been erected on a somewhat less elaborate scale, but perhaps it may be yet shown that laboratories can be fitted up in a simpler and less costly manner than is the general custom at the present time in this country, with gain rather than loss to their efficient working.

It is now becoming generally recognised that, before the erection of a room or group of rooms intended for science laboratories is commenced, it is necessary to fully consider the details and arrangement of the heating, ventilation and fittings which will be employed in order to render the building suitable for the requirements. Otherwise, the after-construction of flues and air-ducts, for heating and ventilating the laboratory, will be found to be expensive, if not impossible. If the arrangement

of all the proposed fittings has been previously thought out and decided upon, all necessary flues, channels, etc., can be formed in the walls and floors when they are being built.

When the attempt is made to convert into a chemical laboratory a room not originally intended for that purpose, much inconvenience and unsightliness is often caused by the drains and pipes, necessitating the whole floor being raised above its original level, or by the fixing of extract flues on the wall-faces.

# CHEMICAL AND PHYSICAL LABORATORIES.

## PART I.

## ELEMENTARY SCIENCE ROOMS.

### SCIENCE ROOMS FOR BEGINNERS.

THE education of young children is, at the present time, undergoing very great changes, owing to the importance now placed on training the eye and hand at the same time as the mind. By practical science work, it is endeavoured to develop and cultivate in them habits of exactness and observation, and facility in reasoning correctly from those observations.

This work is begun at the age of eleven or twelve or even younger. It consists chiefly of some very elementary chemistry, physics and mathematics, for example, simple experiments with such familiar substances as chalk, salt and sand, exercises with weights and pulleys, and the measurement of length, area, mass, volume, etc.

This early practical work is now in a transitional state; it is, therefore, almost impossible to give any reliable and accurate description of the fittings that will be required, or how they are best arranged.

Nevertheless, there is no doubt that whatever is provided should be extremely simple, inexpensive but strong.

Figure 1 is a plan showing a suggested arrangement of the fittings in a room, where the teaching is of this very elementary nature.

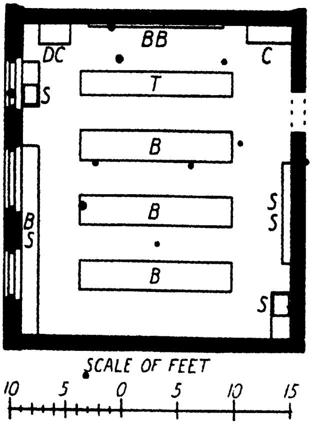



FIG. 1.—SCIENCE ROOM.

B. = Bench.
BB. = Black-board.
C. = Cupboard.
DC. = Draught-closet.
S. = Sink.
BS. = Balance-shelf.
SS. = Shelves.
T. = Table.

The benches are arranged parallel to the demonstration-table. The pupils, who usually work in pairs, all face the teacher; they are probably provided with stools to sit on, or perhaps, in the case of girls, with chairs. The distance between the benches should never be less than 2 ft. 9 in., so as to allow the teacher to have access to every pupil. The length of bench-space allotted to each pair of children would be about 2 ft. 6 in. or 3 ft. The benches would be about 2 ft. 4 in. wide and 2 ft. 7 in. or 2 ft. 8 in. high; deal tops treated with paraffin will generally meet the requirements. A gas-connection should be within reach of each pupil for heating purposes. It is useful to have a rail from which apparatus can be suspended; this can be 2 ft. 6 in. or 3 ft. above the bench and about 1 ft. 6 in. from the front

edge. If cupboards are provided under the bench-top, they can be quite small and must be set back some 6 in., so as to allow space for the knees. Bottles, containing the substances experimented with, can be placed on and below a shelf at the ends of the benches.

Instead of having the sinks against the walls, as shown in the plan, they could be placed at the ends of the second bench. They can be of tarred wood, about 24 in. long, 14 in. wide and 10 in. deep.

Again, if the balances are placed at the ends of the benches, instead of above the cupboards and drawers in front of the windows, there will be less moving-about for the pupils.

The demonstration-table need not be more than 2 ft. wide; a supply of gas is necessary, and, near at hand, a sink with water laid on. On the wall behind the table there must be a "black-board" of ample dimensions. A draught-closet near the demonstrator's table is advisable.

Plenty of cupboards, shelves and drawers are required. Some of the cupboards, preferably glazed ones, can be devoted to apparatus; others can be used for note-books, paper, etc. The latter cupboards, if kept down to about bench-height, can be used as balance-benches.

## LIMITED ACCOMMODATION.

In some schools, the accommodation for science teaching is very limited. There may be merely an ordinary class-room available for the practical work. Perhaps, however, there is one room in which all the practical classes in chemistry and physics (and possibly biology) have to be held.

*Even under these circumstances, provided the science* teaching is on the right lines, it will be possible to educate the pupils to look at things in a rational way, if nothing more than this is done. There is also the hope that some idea of what is always going on around them, some knowledge concerning matter and force and the law and order of Nature will be imparted to them, for that will be of use to them all their lives, whatever their future employment may be.

### Practical Work in an Ordinary Class-room.

Sometimes there is nothing but an ordinary class-room, which is only available at certain times, for practical work.

Fixed benches of the type previously described are obviously out of the question.

Trestle-tables are unsatisfactory, as they occupy considerable time to erect and remove and are usually somewhat unsteady; further difficulties are experienced with the apparatus, gas supply, etc.

Reference may be made here to the wall-benches described by Mr. J. Lomas, A.R.C.S., F.G.S., at the recent conference of science teachers at Manchester. In his paper on "The Fitting-up of School Laboratories," he says: "They consist of cupboards containing shelves placed against the walls and projecting 8 or 9 in. into the room. The doors are hinged at the bottom, and when open form the working-bench. They can be supported by folding brackets or by cupboards placed beneath. A gas-pipe laid along the wall just above the bench, with nozzles for tubing at each working-place, gives sufficient gas supply, and water can be laid on at the corners of the room, in places which would be useless as working-places (*see* **Figure 2**). When closed, the whole resembles a series of cupboards round the

room about 4 ft. 3 in. high, and projecting about 12 in. from the wall."

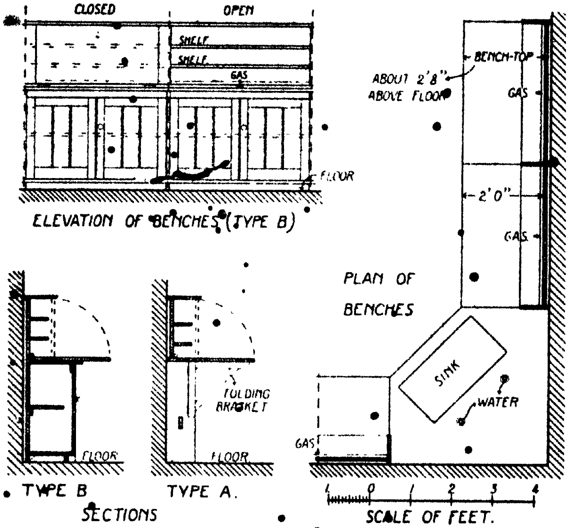



FIG. 2.—WALL CUPBOARD-BENCHES.

## Combined Chemical and Physical Laboratories.

In some instances, by force of circumstances, one room has to serve as both a chemical and physical laboratory. This is a very undesirable arrangement for many reasons; for instance, delicate physical instruments and frictional electrical apparatus may be rendered useless by the fumes and moisture that are inseparable from chemical work.

An attempt must be made here to arrange the benches so that they are suitable for both kinds of

work. The compromise in their structure can be effected by means of a chemical working-bench of the ordinary pattern, except that the sinks have flush covers and the reagent-shelves can be lowered to give a clear bench-top. Fixed suspension-rails are, however, sometimes provided, more especially for the physical students (page 94). In George's patent combined bench an easy and safe method has been adopted for lowering the reagent-shelves and their contents bodily. Sash cords are used, these pass over pulleys and are attached to sliding-weights, which are heavier than the shelves and the bottles; these latter can be caused to descend by a downward pressure, and are kept down by a spring catch.

To lift off and remove the reagent shelves and bottles, whenever the bench is required for physical work, is too long and risky a process to be satisfactory, unless the number of bottles and the size of the shelves are both very small.

### Separate Chemical and Physical Laboratories, but only one Lecture-room.

In many schools, the accommodation for science teaching and practical work consists of separate laboratories for chemistry and physics, but only one lecture-room for the two subjects. As a rule, there are also some small rooms, which are used as store-rooms for apparatus and chemicals, balance-room, dark room, etc.

**Figure** 3 is a plan showing how a chemical laboratory, a physical laboratory, and a science lecture-room, suitable for a small school, can be arranged. Some small subsidiary rooms are also shown, accessible from each of the larger ones.

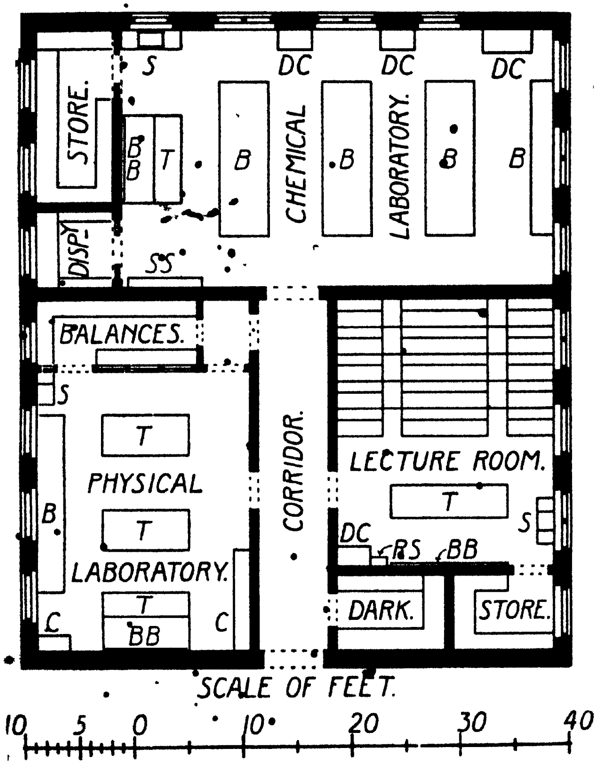



FIG. 3.

B. = Bench.
BB. = Black-board.
C = Cupboard.
DC. = Draught-closet.

S. = Sink.
RS. = Reagent-shelves.
SS. = Shelves.
T. = Table.

**Figure 4** is a plan showing another arrangement of small chemical and physical laboratories which have a lecture-room in common. This has been carried out at Birchfield Road, Liverpool.

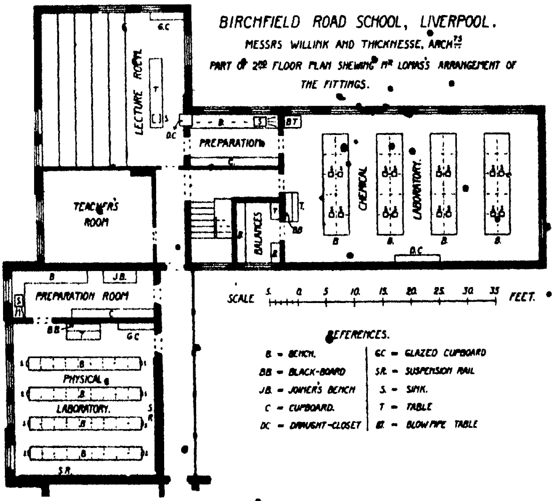



FIG. 4.

# PART II.

# CHEMICAL LABORATORIES.

## GENERAL REQUIREMENTS AND FEATURES.

**Chemistry** can be satisfactorily taught only in a specially designed building, to the efficient lighting and ventilation of which particular attention has been paid.

Where the chemical department occupies only a portion of a building, it should be either on the top floor, or disconnected from the rest of the building by a lobby or corridor, through which a current of fresh air is always passing. The object of this arrangement is to intercept any fumes that may escape from the laboratory.

The **essential parts** are the laboratory and the lecture-room, either separate or combined.

A few additional **smaller rooms** are, however, indispensable: these are required for balances, combustion work, lecture-preparation and stores. An advanced laboratory and a teacher's room should be, where possible, also provided.

In order that the **chemical department** may form a compact whole, the relative position of the various rooms must be carefully considered. The balance and combustion rooms should be next to, or form part of, the main laboratory, but never form a passage to other

rooms; while the preparation-room should adjoin the lecture-room, communication being obtained by a door as near the lecture-table as possible.

In addition to this accommodation, it may be advisable to provide laboratories for special purposes, such as organic analysis, gas and water analysis, metallurgy, physical chemistry, photography, spectroscopic or sealed-tube work. Experiments involving unpleasant fumes, or the use of mercury, can be best conducted in rooms set apart and specially adapted for work of this nature. Then, again, a room may be devoted to collections of specimens, apparatus and models.

## DESCRIPTION OF THE ROOMS.

### THE MAIN LABORATORY.

The **Main Laboratory** should be a large well-lighted room. It is usually lofty, and frequently has an open roof with skylights. By thus increasing the cubic contents of the room, the ventilation and warming are undoubtedly rendered more difficult. On the other hand, the fumes and vapours have a larger bulk of air to diffuse through, and as there are invariably a considerable number of Bunsen-burners being used for heating purposes, the heat and gases from them tend to keep the atmosphere in motion.

No definite height for a laboratory can be given, as it ought to depend on the size of the room and other considerations. If possible, it should be not less than 14 ft. high if it is "ceiled at the level of the wall-plate," that is, if it has a flat ceiling. If, however, the rafters and collar-beam carry the ceiling, the height to the wall-plate should be at least 11 ft. and to the collar-beam not less than 16 ft.

If some, at least, of the light is obtained from the

ceiling or roof, there is all the more wall-space left for draught-closets, shelves, etc.

The windows, walls and floor will be all referred to in detail later on (page 69).

In planning a laboratory and designing the fittings, the keynotes are space and simplicity.

The ideal arrangement of the fittings in all laboratories is one in which the requirements and convenience of the workers have been so carefully studied that they can carry out their experimenting with the minimum amount of moving about. In a school or college laboratory, however, it is sometimes argued that the convenience of the student should not be too thoroughly studied, because, when he goes out into the world, he will be helpless, as he will not find he can get everything he wants by merely stretching out his arm or by turning a tap. Nevertheless, discipline requires that the moving about of the students should be as little as possible, and it also demands ease of supervision for the demonstrator over the whole room, if possible, from every part of it.

It is frequently said that no two teachers hold similar views as to how a laboratory should be fitted up; in fact, opinions on this matter are often very divergent. Hence it must be borne in mind, that, although the capability and teaching powers of one man may be benefited to the utmost, if his laboratory is arranged exactly in accordance with his individual ideas, his successor's efforts may be seriously handicapped.

It is now usually acknowledged that one teacher cannot satisfactorily take more than twenty students at a time for practical work; the Board of Education, in their recent regulations for Higher Elementary Schools, give twenty-five as the maximum.

The principal fittings in the main laboratory are working-benches, sinks and draught-closets. The sinks

and draught-closets may be either against the walls or on the benches.

The disposition of the **benches** in the laboratory is a matter of considerable importance. Working-benches will be referred to in detail later on; here it will be sufficient to mention the two patterns, the single bench and the double back-to-back bench.

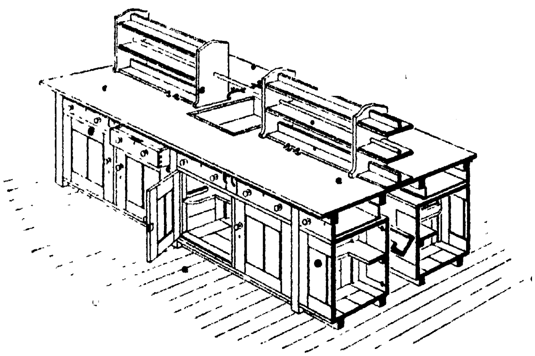


FIG. 5.—DOUBLE WORKING-BENCH.

In a rectangular room there may be

(a) Single benches across the room, like the desks of a class-room, with side gangways (with or without a central one).

(b) Single benches around the room, against the walls.

(c) Single benches against the long walls and a double bench (or benches) down the middle of the room.

(d) Double benches, lengthways, down the room; or

(e) Double benches across the room, with side gangways (with or without a central one).

It may be perhaps worth while to name a few chemical laboratories where these different methods of arranging the working-benches can be seen.

Method (a) is the one it is proposed to adopt in the new County Technical Laboratories at Chelmsford. This arrangement has been followed at the Central Foundation School for Girls, Spital Square, E., and is the one suggested for elementary science rooms.

Method (b) is not a desirable one.

Method (c) is adopted at Battersea Grammar School, Whitechapel Foundation School, and numerous other laboratories.

Method (d) can be seen at Addey and Stanhope School, New Cross.

Method (e) is followed at Tonbridge School (central and side gangways); at East London Technical College general laboratory (one side gangway only); at Chelsea Polytechnic main laboratory (side gangways only); at Woolwich Royal Military Academy chemical laboratory (central gangway only).

The room should be planned for the requisite number of benches, and not the benches for the room.

If the number of students to be accommodated, the allowance of bench-space per student, and the position and width of the gangways are previously determined, the floor-area and size of a suitable room can be readily obtained by plotting the dimensions on paper. By adopting this method, we can not only obtain the correct size of the room, but we can ensure the windows being so placed as to light the benches in the most advantageous manner.

Where double benches are placed across the room and the windows are in the side walls, it is advisable that the windows should be opposite the ends of the

benches, unless the piers between the windows are very narrow or there are large skylights.

From 30 to 36 sq. ft. of floor-area per student, including all gangways, is a suitable allowance for a general laboratory.*

It is usual to give students doing quantitative and organic analysis more bench-space than those doing qualitative analysis, and, of course, advanced students rather more space than elementary ones. The length of bench-space per student is generally from 3 ft. 6 in. to 4 ft., but where large apparatus, as for example, a Liebig's condenser, will be dealt with, about 5 ft. is desirable.

Single benches are usually about 2 ft. 3 in. or 2 ft. 6 in. wide from front to back.

Double benches vary in width from 4 ft. 6 in. to 5 ft.; they should be sufficiently far apart to allow a person to readily pass between two students, who are working back-to-back, even though opposite cupboard-doors are wide open; this will require a distance of from 4 ft. 6 in. to 5 ft. Benches should be from 5 ft. to 7 ft. distant from walls, from the face of which draught-closets, sinks, etc., project.

A **Demonstrator's Table**, raised on a low platform, should be provided in the laboratory for purposes of supervision, and in order that it may be used as a lecture-table. The best position for it is at one end of the room when the benches are arranged according to methods (**a**), (**c**) and (**d**) (see page 12), and at the side of the room with method (**e**). To place wall-benches all round the room [method (**b**)] is not a good

* The Board of Education require that a Higher Elementary School Laboratory should afford 30 sq. ft. of floor-space for each scholar.

arrangement, and should only be resorted to in a very narrow room.

The table should be about 8 ft. long and 2 ft. 6 in. wide, with the platform extending, at least, 3 ft. 6 in. behind it. It is usual to make the platform from 6 to 12 in. high, and it is better not to exceed this limit, as a rise of more than two steps is inconvenient; the height of the platform should be regulated, to some

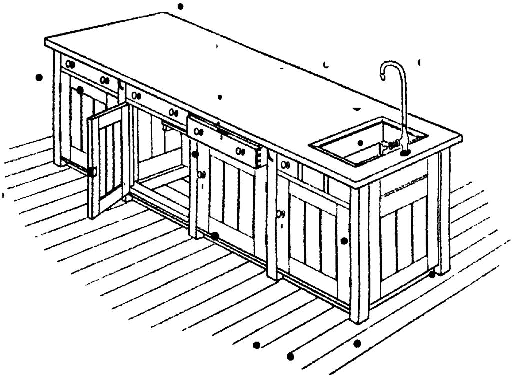


FIG. 6.—DEMONSTRATOR'S TABLE.

extent, by the distance of the furthest benches. A black-board is a very necessary requirement.

The simplest possible provision to enable lectures to be held in a laboratory is a black-board fixed against the wall with a clear floor-space in front of it where the students can stand. If wished, a demonstration-table and some desks, at which the students either stand or sit, can be placed in this space.

A small portion of the laboratory is sometimes divided off, to form a **Dispensary** or store for the

more expensive and less frequently-used chemicals, in order that they may be under the control of the demonstrator.

### Balance-room.

The **Balance-room** should be readily accessible from the laboratory, but it must be remembered that the fumes of the laboratory are injurious to the balances; for this reason, it is better that this room should not be entered direct from the laboratory. It should be particularly well-lighted, both naturally and artificially. When the balance-room is adjacent to the laboratory, a window is, sometimes, inserted in the intervening wall, for purposes of supervision. For the same object, the balance-room is often separated from a corridor by a glazed screen.

**Balances** require to be supported so as to be free from every possible source of vibration; this condition is best obtained by placing them on shelves firmly fixed to the walls.

It is customary to allow one balance to about every ten or twelve students that can be accommodated in the laboratory.

The balances should be situated where there is little passing of the students to and fro, otherwise it is difficult to weigh accurately, and the balances are disturbed by the air-currents caused by these movements. Nevertheless, this room is sometimes used as a reading-room and reference library; a table, chairs and bookcase are then required.

### Combustion-room.

The combustions are usually conducted on stone wall-benches, over which it is advisable there should be hoods communicating with extract flues. The floor should be of cement or other incombustible material.

## STORE-ROOM.

**Stores** consist of both apparatus and chemicals, and these are best kept in separate rooms, which, however, may communicate.

The apparatus, being mostly in the form of empty glass vessels, is light in weight, but to be readily accessible occupies much space. Shelves (solid and skeleton), bins, cupboards and drawers should be provided for the various apparatus. The chemicals, being chiefly in considerable quantities, are heavy and require strong shelving. A small working-bench at which the students' reagents can be made up and a writing-desk for the use of the storekeeper are useful adjuncts. In order to impede those requiring reagents and apparatus from entering the room, a counter is often placed just inside the room, or the door is hung in two heights with a narrow shelf on the top of the lower half.

## LECTURE-ROOM.

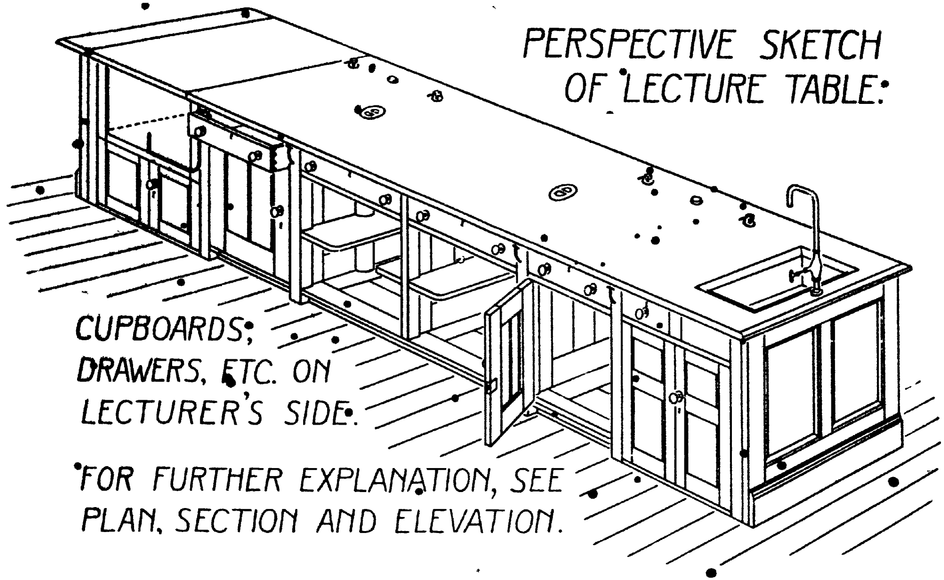
One or more **Lecture-rooms** will be required unless all the lecturing is done in the laboratory. The lectures are, to a considerable extent, supplemented by both experiments and the exhibition of specimens, models and diagrams. Sometimes both a chemical lecture theatre and a chemical lecture-room are provided, the only difference between them being in the amount of accommodation and the completeness of the lecture-table fittings. The former may be used for large gatherings of students and scientific evening lectures, and the latter for the ordinary classes where the experiments are not so extensive or elaborate.

The **Seats** should be carefully arranged, preferably on the isacoustic curve, in order to ensure the occupant of every seat obtaining an uninterrupted

view of the experiments which are being performed on the lecture-table. If the lecturer faces the long side of the room, it is best to divide the seats into three ranges, with the central seats parallel to the table. The rising gallery for the seats can be generally constructed so as to permit the space beneath being used as a room for stores or for optical work.

The **Lecture-table** is the most important fitting. As students occasionally gather round the lecture-table, after the conclusion of the lecture, to examine specimens or apparatus more closely, it is not advisable that the front bench should be less than 5 ft. from the table; besides, if the height of the lecture-table is fixed, the nearer it is to the first bench the greater is the inclination of the seats. The lecturer should be able to easily reach across the lecture-table, therefore 3 ft. is the maximum width; he generally considers that, within reasonable limits, it cannot be too long. A passage-way, however, is convenient round the table, and if this curtails its length too much, hinged flaps on folding brackets may be fixed at the ends for occasional extension. The lecturer requires plenty of space behind the table, but he must never be more than a few steps from the black-board; from 4 ft. 6 in. to 6 ft. in the clear is a good allowance for the width of this space. The preparation of a lecture necessitates a considerable amount of carrying of apparatus, etc., between the preparation-room and the lecture-table, therefore a difference of floor-level is unadvisable; in other words, the lecture-table should not be placed on a platform if it can be avoided.

A large **Draught-closet** is often provided in the back-wall of the lecture-room, accessible on the other side from the preparation-room. As the students experience


PERSPECTIVE SKETCH
OF LECTURE TABLE.
CUPBOARDS,
DRAWERS, ETC. ON
LECTURER'S SIDE.
FOR FURTHER EXPLANATION, SEE
PLAN, SECTION AND ELEVATION.

considerable difficulty in seeing experiments conducted there, the down-draught flues usually provided in the lecture-table are generally relied on, and the draught-closet is merely used as a safe place where a flask or other vessel emitting objectionable fumes can be placed, immediately it is finished with, instead of carrying it out of the room. The other fittings on the back-wall of the lecture-room will be referred to later under the heading of "Details of Fittings."

**Lantern slides** are now much used by lecturers. If a lantern with a short focus lens is employed, it can probably stand on the lecture-table, otherwise it is necessary to provide a special platform; which, for some experiments, requires to be independent of all floor and gallery vibration. The lantern-screen should be arranged so as to avoid having to throw the students' seats into darkness whenever pictures are projected on it; the absence of light prevents the students from taking notes, and may even suggest to them an opportunity for a disturbance.

## PREPARATION-ROOM.

A **Preparation-room** should be provided, if funds and space permit; it should communicate with the lecture-room by a door as near the lecture-table as possible. If it also adjoins the laboratory, so much the better.

It is a great convenience to have a room where the apparatus required for the lecture experiments can be selected and set up, instead of having to do this entirely on the lecture-table itself. Besides, in this room can be kept all apparatus, chemicals, specimens, models and diagrams, that are in constant use for lecture purposes. These can be stored in glazed cupboards and drawers against the walls.

The preparation of the chemicals and the fitting-up of the apparatus are best done at a working-bench, while a large sink, with ample draining-board is required for the cleansing of the apparatus. If the accommodation allows, a large table in the centre of the room is very useful, on which to set out apparatus and prepare diagrams. This latter work, however, is sometimes done in the balance-room.

### Advanced Laboratory.

The **Advanced Laboratory** is usually fitted very similarly to the main laboratory, but in most instances a much smaller room suffices. The principal fittings are working-benches, sinks and draught-closets, with perhaps a combustion-bench.

### Teacher's Room.

The **teacher** requires a room, or, better still, two adjoining rooms, for use as a study and a private laboratory: the former where he can read, write and interview students, and the latter where he can, without fear of disturbance, carry on any experimental work he may be engaged upon.

The study requires the usual writing-table, book-cases and cupboards, and the laboratory a working-bench, draught-closet, sink, cupboards and drawers.

### Rooms for various Special Purposes.

The **Organic Analysis Laboratory** requires working-benches, sinks, large draught-closets, and combustion-benches with extract hoods over. For this work, students need a considerable amount of bench-space.

**The Metallurgical Laboratory** resembles a workshop rather than a laboratory. The chief features are

the muffle and wind furnaces with hoods over to carry off the heated air and fumes; gas and coke are used as

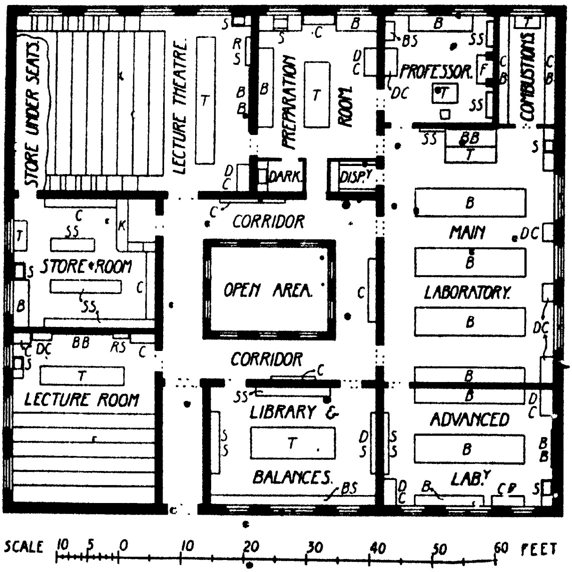



FIG. 8.

B. = Bench.
BB. = Black-board.
CB = Combustion-bench.
C = Cupboard.
DC. = Draught-closet.
F = Fireplace
K. = Counter.

S. = Sink.
BS = Balance-shelf.
DS. = Desiccator-shelf.
RS. = Reagent-shelves.
SS. = Shelves.
T. = Table.

fuel. Working-benches and draught-closets are also required.

**Dark Rooms** for photographic, spectroscopic or photometric work are often not much more than large

cupboards with no means of ventilation. Particular care should be taken to obtain good ventilation without the admission of daylight.

**A Room** for operations requiring the use of considerable quantities of **mercury** should have a cement or asphalte floor, with a shallow semicircular groove in it, into which the spilled mercury can be swept. To prevent loss of mercury between the joints of a boarded floor, a good plan is to cover it with linoleum cut a little too large for the room, and turned up against the walls to avoid square angles.

Operations involving unpleasant **fumes** are best conducted in a room entered only from the external air, or one with windows on all sides of it. A flat roof, if available, is often utilised for such experiments as are best conducted in the open air.

**Sealed tubes** are usually heated in small stone or brick chambers provided with sliding iron doors and flues.

**Figure 8** is a plan of a Chemical Department suitable for a college or technical school. It illustrates the suggestions that have been made as to the relative position of the different rooms and the arrangement of the necessary fittings.

## DETAILED DESCRIPTION OF THE FITTINGS.

### THE MAIN LABORATORY.

**Working-benches.**—*The height* of the bench-top should be governed by the rule that the student, when standing at the bench, can carry on his work with his fore-arm approximately horizontal. This is found to

be 2 ft. 9 in. or 2 ft. 10 in. for students up to about sixteen years of age, and 3 ft. for all others.

*The width* of the bench-top from front to back is regulated by the distance a student can easily reach, without bending over the bench. This is about 2 ft. 3 in., but as stated above, double benches vary in width from 4 ft. 6 in. to 5 ft.

*The length* of the bench-top allotted to each worker was referred to in connection with the planning of the laboratory (page 14).

The chief advantage of *double benches* over single ones is the economy of the floor-space, woodwork and pipes; while the only disadvantage is that the class faces in two opposite directions, and therefore is not so readily instructed from the demonstrator's table.

*Under the bench-top* are usually a row of drawers with cupboards below. These are provided for the sets of apparatus with which the students are entrusted. The number, and therefore the size, of drawers and cupboards, below each working-space, is influenced, to some extent, by the number of students who work at each place at different times. There are generally two drawers and two cupboards to each working-space. If there are more than two students to each place, various expedients can be adopted, such as specially small retort stands, etc., or a common cupboard for the stronger apparatus but separate drawers for each student.

Convenient inside dimensions for the *drawers* are 4 in. deep, 18 in. wide from front to back, and 15 in. long. A wooden turn-button, screwed either to the back of the drawer or to the frame, is convenient in preventing the drawer from being unintentionally pulled out too far, and yet allows it to be removed for cleaning, etc. In order to prevent small articles from shifting

about, a division across the drawer about 3 in. from the front and 3 in. high may be found advisable. Turned wood drawer-knobs about $1\frac{3}{4}$ in. diameter are preferable to metal drawer-pulls; the latter, owing to the acid fumes in the atmosphere, soon become unsightly, but bronze metal ones less so than polished brass. The objection often raised to knobs is their projection, especially when the drawer is partially open; this can be overcome by recessing them, but an unduly thick drawer-front is then required. If it is wished to dispense with locks on the drawers, a hardwood spring can be fitted to the underside of the bottom; the drawer can then be opened only from inside the cupboard below.

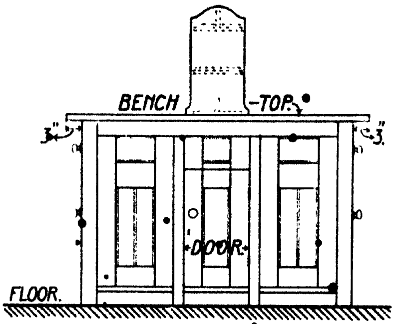
A small *writing-desk* can be sometimes provided. It may be a very shallow drawer, the front of which can be let down into a horizontal position: another plan is to have a sloping board about 10 in. by 12 in., which is kept in a special drawer.

The *cupboard* should be high enough to take a retort stand, and be fitted at the back with a shelf about 6 in. wide and 12 in. above the bottom. It may be found that by continuing the shelf along the sides the usefulness of the cupboard is increased; these side-shelves need not be more than 4 in. wide. The cupboards are frequently recessed 4 or 5 in. back from the face of the drawer-fronts, in order to allow space for the knees when the students require to sit down to do blowpipe work or write out rough notes of experiments. This reduction in the size of the cupboard is not generally serious, as it is difficult to reach to the back of a deep one. A convenient size is 22 in. high, 18 in. wide from front to back, and 17 in. long. Sometimes a wooden tray sliding into the upper part of the cupboard takes the place of the drawer. A turned wood knob to the

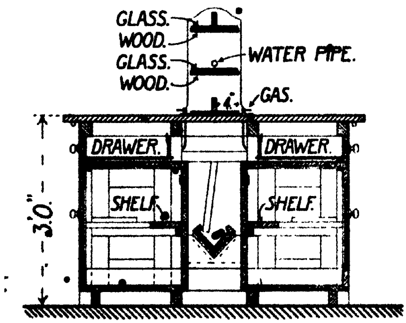
door is preferable to a flush ring, and avoids the use of metal. The lock is often subjected to rough usage, and, therefore, should be simple and strong in construction. There are two ways of avoiding the inconvenience due to locks getting out of order and students losing the key with which they have been provided. Either the cupboard is fitted with a staple fastener, or the drawer and cupboard are secured by a flat metal bar pivotted at one end, the student in both instances providing the necessary padlock. There is the disadvantage, however, that the demonstrator loses control over the contents of the cupboards and drawers. In order to keep the cupboard-door closed when unlocked, a ball-catch may be fitted. In addition to a number painted on the door, a card bearing the student's name and class is sometimes slipped into a card-holder. When the students are not given keys, but the assistant opens the cupboards before they enter the laboratory, each class can be indicated by a card of a distinctive colour.* The name cards are, however, generally fixed against the reagent-shelves only. Where a stock of glass-tubing is allotted to each student, there should be provided for it a long compartment, about 3 in. square inside, the full width of the double bench, and accessible from the cupboard; these compartments are usually constructed in pairs, alternate ends being open. The closed ends should be fixed with screws in order to facilitate removal for cleaning.

If waste-pipes or channels from the sinks are taken down the centre of a double bench, access to them should be practicable through the cupboards. A good plan is to have the cupboard-shelf to slide out, and to

* As at Felsted School, Essex.




END.




SECTION.

[To face page 26.

make the greater portion of the back easily removable by being merely held in position by two wooden turn-buttons; only the backs of alternate cupboards need take out.

*Waste-box.*—When there are sinks on the benches, only short drawers could be fitted opposite them, owing to the depth of the sinks. This space is, therefore, frequently devoted to a receptacle for solid rubbish, such as used filter-papers and broken glass; for this purpose a wood tray, preferably of teak, is most suitable.

As the contents are unsightly, this box is often placed either behind a flap which is hinged at the top and opens inwards, or else in a separate cupboard, which also permits of access to the waste-pipe down from the sink. This practice, however, of placing the rubbish box out of sight is objectionable. It is better either to provide some small trays of teak or glazed ware on the bench-top, or to have a few larger boxes or pails * placed on the floor in convenient positions, such as under the draught-closets: they are then more likely to be periodically emptied, and their surroundings kept perfectly clean. In some instances, it is possible to form a recess in which the stool can be placed when not in use.

A *toe-space*, or recess, about 3 in. high, should be formed at the floor-level below the front portion of the cupboards; this avoids the unsightly appearance due to the students' feet coming in contact with the woodwork, and allows the students to stand close up to the bench when at work. The depth of this recess, of course,

* Indurated Fibre Ware is unbreakable and cannot be dented like iron or zinc. It is manufactured by Messrs. Cordley & Hayes, of New York, and can be obtained through Millard Bros., of Houndsditch.

varies with the projection of the bench-top beyond the cupboard front.

Under certain circumstances, it is sufficient to provide one or more shelves in place of the drawers and cupboards just described; the bench-top can be then supported on cast-iron standards,* which, however, require constantly coating with some suitable material to prevent corrosion, but complete openness is obtained with this arrangement.

*Materials.*—The fronts and ends of the benches are most frequently made in pitch-pine, although stained American whitewood is coming somewhat into favour, as its appearance is good and it is cheaper and more easily worked than pitch-pine. Red deal, orham,† wainscot oak, and American walnut are also used for this purpose.

In order to avoid crevices and angles, in which dust, etc., may accumulate, it is advisable to have as few mouldings as possible, and only "flush" panels.

The *bench-top* is called upon to resist the action of acids and alkalies and to withstand the heat from Bunsen-burners, heated flasks,‡ etc. Teak is the wood that is almost invariably used. Mahogany, oak, pitch-pine, and even deal are occasionally met with as bench-tops, and these, if properly cared for, may be satisfactory, or, at any rate, better than teak which is not properly seasoned. Greenheart is said to be the best wood known for this purpose, but the great cost of working it up, owing to its extreme hardness, renders its use prohibitive in many instances.

In almost every laboratory the bench-top is

* As at Royal Military Academy, Woolwich.

† Orham is elm grown in certain parts of the Southern States of America.

‡ These should be always placed on a square of asbestos millboard or a tile kept specially for this purpose.

periodically treated in some way to render the wood non-absorbent and free from all tendency to crack. Opinion as to the best way to attain this condition varies very widely. High-melting paraffin, dissolved in xylol and rubbed in, or melted and ironed in, forms a very good protective coating, but it may be affected by heat from gas-burners or hot vessels. Therefore, in some laboratories, either linseed oil (raw or boiled), beeswax and oil, beeswax and turps, or oil followed by a coat of black varnish are preferred.*

Other materials, besides wood, have been used for the bench-top, as for example, lead, glass, slate and stone.

When lead is employed, a hardwood fillet is screwed to the edge of the bench-top, projecting up about $\frac{3}{4}$ in., and the lead is dressed over the top of it; sometimes the lead is turned down over the square edge of the bench-top before the fillet is fixed, the joint being made with red and white lead. The former method is, however, the preferable one. Lead does not make a very satisfactory bench covering, as it soon looks dirty and "rucks up" when heated vessels are placed on it.

If glass is used, it should be about $\frac{3}{8}$ in. thick and supported on strips of corrugated rubber; the edges can be protected by a narrow wooden border or frame.

There are but few natural stones in this country that are sufficiently fine grained and otherwise suitable for use as a bench-top. On the Continent enamelled volcanic lava† is frequently used, and in America alberene stone, a natural variety of soapstone.‡

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* Black varnish is used at Battersea Polytechnic.

† To be obtained from Ingenieur Seurat, St. Martin-lès-Riôm (Puy-de-Dôme).

‡ Alberene Stone Co., 393, Pearl Street, New York.

*Shelves for reagents* are required principally for qualitative analysis work.

As elementary students now begin with descriptive work and simple quantitative experiments, there may be only a few, if any, reagents provided at each working-place; a movable tray (**Fig. 10**) for the bottles may then suffice.

These shelves are generally placed down the centre of double benches and along the back of single and wall-benches. If, however, they are arranged across the bench, one set of reagents may serve two adjacent students, neither of whom has to reach across his work to take a bottle off its shelf.* Reagent-shelves, unless kept low, interfere with the general supervision of the laboratory, but they are often useful in impeding students from wasting their time in talking across the bench or squirting one another with water out of their wash-bottles.

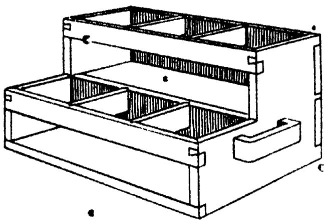


FIG. 10.

Either wood or plate-glass is usually employed for these shelves. Wood shelves may be kept cleaner and somewhat protected from the action of the contents of the bottles, if the upper surface is covered with either sheet, cast or plate glass, or white glazed tiles; the underside of this glass is sometimes painted white for the sake of the appearance, but this paint requires constant renewal.† The supports for the shelves

* An arrangement adopted by Mr. Earl, at Tonbridge School.

† Sometimes the bottles containing the four acids and caustic soda stand in a very shallow tray of white glazed ware.

are generally of wood, but cast-iron is occasionally employed.

As the liquid reagents are usually provided in 10 oz. bottles, 4 in. is a convenient width for the shelves. There are generally three shelves, but their number depends partly on their length. For elementary work, one shelf about 11 in. high may be perhaps found sufficient. A certain extent of shelving unoccupied by reagent-bottles is useful for placing flasks, etc., in a safe position, as for example when a student is doing a fractional distillation. For general purposes, a total length of reagent-shelves of from 6 ft. 6 in. to 7 ft. is found convenient. The vertical distance between the shelves is usually about 7 in. in the clear.

On double benches a central division or back between the two sets of shelves is advisable. This partition may be of wood or glass; at all events, the bottles must be prevented from encroaching on the adjoining shelf by either a wood fillet or some other form of stop. Gas or water supply-pipes can be often run so as to conveniently act as a back-stop for the bottles. If the lowest shelf is placed on the bench-top, it will prevent the possibility of an upper one being damaged by a lighted Bunsen-burner being unintentionally pushed under it. A narrow wood fillet could be used equally well to prevent such an accident, but it renders the bench-top less easy to clean thoroughly. If the reagent-shelves are made to lift bodily off, the bench can be used for experiments with very large apparatus, and the bench-top can be more easily cleaned, or treated with paraffin or oil.

There are two ways of economising space by providing *fixed apparatus-stands*, instead of giving each student the usual independent supports for filters, retorts and flasks.

A *filtering arm* may be fixed to the underside of one of the reagent-shelves so as to slide back when not in use; it should be made in hardwood and pierced with one or two holes of considerable size for the reception of the funnel.

A vertical iron rod about 24 in. long and three-eighths of an inch diameter may be fixed to the reagent shelf-brackets; suitable rings for supporting flasks, retorts, etc., can be clamped to this rod at any desired height. Possibly this rod may be dispensed with and the rings clamped to the standard carrying the gas or electric lights illuminating the laboratory. Another method is to bring the gas for heating purposes down these uprights, the horizontal pipes overhead may be useful for suspending apparatus from.

If there is more than one set of reagents at each working-place, it may be found advisable to provide locking bars; this prevents a student having access to bottles for the contents of which another student is responsible. Sliding or hinged glazed fronts should be avoided. Sometimes a space at the level of the reagent-shelves can be arranged for, where the student can place his sheet of analysis tables or examination questions, so that it can be easily read and yet get less soiled than on the bench-top.

**Bench-sinks.**—Sinks are generally provided on the benches, but for elementary work they are not very much needed, on the benches at any rate.

They are disposed in various ways. Occasionally each student has a separate sink. Generally there is a sink between each pair of students, and consequently one placed across a double bench may be within the reach of four students. By providing sinks at the ends only of the benches, the waste-pipes and drains are

generally simplified and rendered more accessible. With a long bench, however, this arrangement necessitates several of the students having to leave their places whenever they require to use a sink. Hence, if the extra space can be afforded, it is better that double benches should accommodate only four students.

Sinks are generally made of stoneware or fireclay, with the inside glazed and of a white or cream colour, but sheet-lead, enamelled iron and wood are sometimes employed. Occasionally they are circular, about 10 in. or 12 in. in diameter, but more often rectangular. For the use of two students, a sink about 13 in. by 9 in. inside is found convenient, but when it is placed across a double bench, so as to be within reach of four students, it should be about 18 in. by 12 in., or 20 in. by 10 in. The depth measured inside need not be more than 5 in. or 5½ in.

When the material of the sink is of an unyielding nature, such as stoneware, fireclay or iron, the fracture of glass vessels is rendered less frequent by placing on the bottom of the sink a piece of wood, preferably teak, perforated with a number of small holes. This board also acts as a strainer and prevents, to a great extent, solid matter from getting into the waste-pipes.

The chief disadvantages of stoneware sinks is their comparatively high price, their liability to get fractured and the difficulty of connecting the waste-pipe. Enamelled iron sinks are usually cheaper, but very short-lived.

Wood sinks are made of American whitewood, teak, sycamore and birch. If lead-lined, no solder must be used, all joints must be made with the blow-pipe.

A sink, constructed of wood, either lead-lined or pitched, is more likely to remain watertight if always

kept damp, than if it is sometimes wet and sometimes dry; hence the advantage of having the outlet 2 or 3 in. above the bottom. There are the additional advantages that any strong acids thrown into the sink are diluted by the water always retained there, before they pass down the waste-pipe, and also that solids have a chance of settling before they are carried down the waste-pipe. The disadvantages are the dirty appearance of the contents of the sink and the almost unavoidable splashing whenever the sink is used.

With the view to shield the bench-top from splashings, a throated projecting rim is often formed round the inside of fireclay sinks; while, with the same object, the sides of wooden ones are sometimes made to slope inwards.

Sinks are best fixed under the bench-tops, then, if the under-side of the bench-edge is throated, spilt liquids can be safely washed direct into them; but they are difficult to get out and replace, if fractured. Owing to the slight irregularity of shape, which is unavoidable in the manufacture of stoneware sinks, it is not easy to make a neat and permanently watertight joint when they are let in flush with the bench-top.

Occasionally the sinks have wooden covers, which may be either loose, sliding or hinged. It is difficult to know what to do with loose covers when they are removed, unless special cupboards or drawers are provided, in which each one can be placed. Sliding covers necessitate the sliding-forward of a considerable portion of the bench-top, part of which has to be hinged to fall over the front of the bench when the sink is used, and the hinges, unless unusually strong, soon get broken. This same disadvantage applies even more forcibly to hinged covers. A hole should be drilled through the cover immediately below the nozzle

of the water-tap, so that water, dripping from the tap, can pass into the sink when the cover is in its place.

A loose perforated plug is useful for fitting into the outlet of the sink, when a depth of water is required or when a reduction in the size of the outlet is advisable. The plug should be made of wood, vulcanite, or sheet-lead, and not stoneware, which is heavy and brittle.

For advanced work it is often a convenience to have a channel about 4 in. wide and 2½ in. deep down the centre of double benches, and along the back of wall-benches. It can be of glazed ware or wood lead-lined, and can deliver into the sinks. This channel is useful for getting rid of the waste-water from condensers, etc.

If on the double benches this channel is continuous and is 9 in. wide and 5 in. deep instead of only 4 in. by 2½ in., the sinks can be dispensed with altogether.* This trough need not be open for its entire length, but can be provided with a cover in short lengths, which can be easily slid along or lifted off as desired. The disadvantage of this arrangement is that a student has some difficulty in reaching over to this trough and to the water-taps above it, even if the bench is of the usual width.

**Sink Waste-pipes.**—It is most important that the waste-pipes from the sinks are easily accessible throughout their entire length, so that any leakage or stoppage that occurs may be immediately noticed and readily located and rectified. Provision must be made for arresting all solid matter that may be carried down the outlet of the sink before it enters the closed waste-pipes and drains.

Where there are several sinks on a working-bench, each sink should deliver into a long open trough, at

* As at King Edward's High School for Girls, Birmingham.

the end of which is a receiver or catch-pit, or else there should be a receiver below each sink. To avoid the use of a lead or stoneware pipe, which may get choked and is not easily detached, a sloping square wooden tube, tarred inside, may form the connection between sink and trough. The open trough, which must be laid to a fall, is usually constructed of wood, lead-lined and coated with pitch inside, or merely pitched inside. If it is **V**-shaped, there is only one joint instead of the two which a square section necessitates, but its capacity is smaller. Sometimes a series of glazed stoneware half-round channels are employed, but they have numerous joints, are heavy, and cannot be readily removed for repairs.

The receiver at the end of the trough can be either of glazed stoneware or of wood lead-lined; a convenient size is 13 in. long, 8 in. wide, and 7 in. deep inside; it must be arranged so as to be easily removed from time to time to be emptied and cleaned out. When there is a receiver below each sink, it can be somewhat smaller than the one described above; if it is made of glazed stoneware, a cylindrical receiver about 5 in. diameter and 10 in. deep is found very suitable.

If the waste-water from the sinks is taken straight down into open glazed channels laid in the floor, any bad-smelling liquids passing along those portions not under the benches are likely to be objectionable, especially as the fall that can be given to the channels is usually very small, and covers are unadvisable except in the gangways. The channels should not be less than 6 in. wide, so as to allow of cleansing with a broom when required.

**Bench Draught-hoods.**—In some laboratories draught-hoods or small draught-closets are fitted on the

bench-tops between each pair of students. The object of these is to immediately get rid of the unpleasant fumes and vapours evolved by the students at their benches, in order to avoid, as far as possible, vitiating the atmosphere of the laboratory.

It is advisable to keep these hoods and closets as small and low as possible, in order not to interfere with the general supervision of the laboratory.

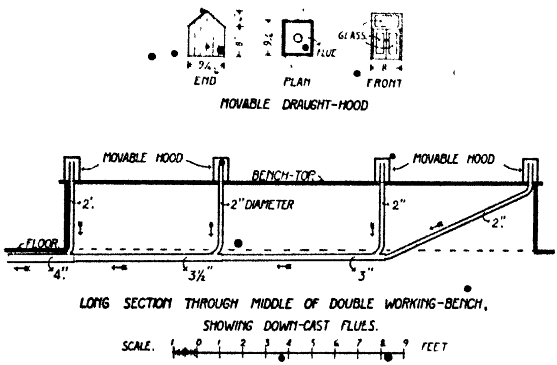



FIG. 11.—DRAUGHT-HOODS ON A WORKING-BENCH.

Their employment must entail the minimum amount of trouble on the part of the students, otherwise it will be found they are not always used when they should be.

The extract flues can be of metal, galvanized and Angus Smithed, of glazed stoneware, or of wood, tarred inside or lead-lined. They should be made to lift out and the flue closed by a plug at the level of the bench-top, for the reasons set forth when discussing reagent-shelves. The hoods may be simply plates of thin glass or enamelled iron laid on sloping wooden

brackets fixed to the sides of the flues. When hoods are to be provided, the flues should be carried up about 20 in. above the bench-top. The lower edges of the hoods should project about 7 in. and be 12 or 14 in. above the bench-top. The most satisfactory inlet to the flue is a narrow slit which can be closed by a wooden slide.

If small draught-closets are preferred, they need not be more than about 12 in. by 10 in. inside, and about 14 in. high; the top and sides should be glazed. It is often sufficient if, instead of a lifting sash occupying the whole of the front, the lower part to the height of 9 or 10 in. is left open;* the remainder of the front can be a glazed flap, hinged at the top to open outwards. It is then advisable to be able to close the mouth of the extract flue when it is not in use.

In **Figure 11** are shown some small draught-hoods or closets which are readily lifted off the bench when not required. These are made by Messrs. Brown & Son, of Charlotte Street, N. They will be used at the South Hackney Institute.

**Gas-fittings on the Benches.** — Each student should have two gas connections suitable for attaching rubber-tubing. The nozzles may be either at the front or the back of the bench; in both cases the taps should be at the front, so that the student does not have to reach over his work to regulate the current of gas. The most convenient place for the gas-pipe is under the front edge of the bench-top. If the projection of the top beyond the front of the bench is 2½ in. or 3 in., sufficient protection is afforded for the taps on the branches. If the nozzles are to be at the back of the

* As at Bedford College, London.

bench, the branch-pipes can be taken through the divisions between the drawers or cupboards; if at the front, the taps and nozzles can be fitted directly on the main pipe and the rubber-tubing passed through holes drilled in the bench-top.

The gas-nozzles, water-standards, and other metal work on the benches, if of brass, require almost daily polishing in order to look decent; hence it is better to have them of oxidised gun-metal, heavily lacquered. A cheaper arrangement is to use iron fittings black-enamelled and stoved, a simple treatment that can be carried out at almost all bicycle works.

**Water Supply to Working-benches.**—There must be above the sinks at least one water-tap for each pair of students; in addition, it is generally advisable to provide for each student a small branch-cock to be used for connecting to a condenser or filter-pump. Low-pressure is, however, best for use in a condenser, and high-pressure for filtering purposes. These branch-cocks, like the large tap, should point down towards the sink, in case of accidents. The nozzle of the large tap should be not less than 15 in. above the bottom of the sink.

**Control of Gas and Water on the Benches.**—The entire supply of gas and water to each bench should be controlled by stop-cocks at one end of the bench. Then, when any of the benches are not being used, all leakage of gas and waste of water can be avoided, by closing these stop-cocks, without having to carefully examine each individual tap. This provision, however, does not render it advisable to dispense with stop-cocks on the gas and water mains where they enter the laboratory.

To avoid possible errors, the taps on the gas and water pipes should be very different in appearance, for instance, all gas-taps could be lever taps, and all water-taps, screw ones. It is a good plan to paint the various pipes distinctive colours, such as gas red, low-pressure water blue, high-pressure water grey, steam brown, etc.* These suggestions apply not only to the benches but to the whole laboratory.

"The gas supply-pipes in chemical laboratories should be always very much larger than is ever required. It is not a question of the possibility of obtaining sufficient gas but that the supply shall be large enough to admit of great variation in the demand without interfering with operations in progress. . . . A laboratory with a deficient and ungoverned supply lacks one element of precision without which experimental work is of little value."†

## Examination Laboratories.

In laboratories used only for examinations, the benches are generally arranged somewhat differently from those in an ordinary chemical laboratory.

The leading principles are these, that each candidate has ready at hand all the apparatus, reagents and chemicals with which he can reasonably expect to be provided, so that he has no cause for leaving his place, that he is unable to communicate with, or "crib" from, any other candidate, and that the examiner has free access to each candidate and perfect supervision over the whole laboratory. As there are usually at least two different sets of substances to be analysed or

* These are the colours usually adopted.

† From "Coal Gas as a Fuel," by Thos. Fletcher, 5th edition, p. 209.

experiments to be made, it is not essential that each bench is isolated; besides, copying is, after all, of little benefit in practical chemistry.

One of the best arrangements is to have the benches long enough to accommodate two candidates, and to face them all one way, or towards the middle of the room if it is a large one.*

The bench, although essentially similar to those already described, should perhaps be slightly larger, say 5 ft. long and 2 ft. 9 in. wide; as this is rather wide to reach across, the more distant part of the bench-top may be used as a shelf for bottles for the next candidate in front. To avoid loss of time, the candidate should be able to see at a glance where each piece of apparatus is stored; hence the advantage of cupboard-doors that are glazed, and drawers that have divisions for retaining each article in its right place. The space occupied by the candidate need not be more than 2 ft. 9 in. or 3 ft. wide in the clear, while gangways, between the bench-ends, should not be less than 4 ft.

If double benches are adopted, the division down the middle of them should be non-transparent and about 3 ft. high. As the examiner should be able to pass freely up and down between the candidates, the gangways should be, if possible, 6 ft. or 7 ft. wide.

In examination laboratories, there is a stool at each working-place; these are sometimes fixed to the floor.

**Draught-closets for General Purposes.**—These are enclosures within which operations involving the production of fumes and gases can be conducted without harmful effect on either the operator or the general

* As at the University of London, South Kensington.

atmosphere of the laboratory. It is usual to provide one of these closets to about every eight or ten students that can be accommodated in the laboratory.

If there are an insufficient number of draught-closets in the laboratory, or if they are not placed in the most advantageous positions, it may be found that a student is tempted to carry on at his bench work which should be done only in a draught-closet; he may thus cause considerable inconvenience and annoyance to all the other students in the laboratory.

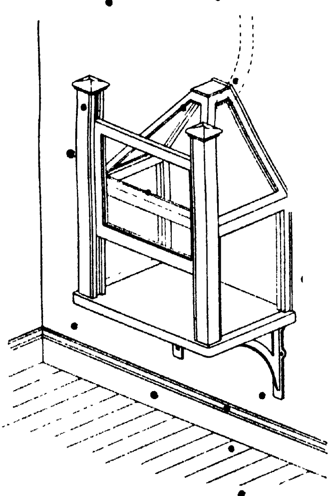


FIG. 12—SMALL DRAUGHT-CLOSET.

They are generally placed round the room near the ends of the benches, either on the face of the walls or in recesses specially provided for them. Occasionally they are constructed in front of the windows; although they may then project less into the room and be better lighted during daylight, the ventilation of the laboratory by means of these windows is interfered with. When the draught-closets are against the walls, the extract flues are more easily provided and less conspicuous than when the closets are on the benches or elsewhere in the middle of the laboratory.

It is often convenient to have several small draught-closets about 2 ft. 6 in. long by 1 ft. 7 in. from front to

back inside, and a few larger ones about 4 ft. long by 2 ft. from front to back inside (*see* **Figures 15 and 16**).

The height of the bottom above the floor depends

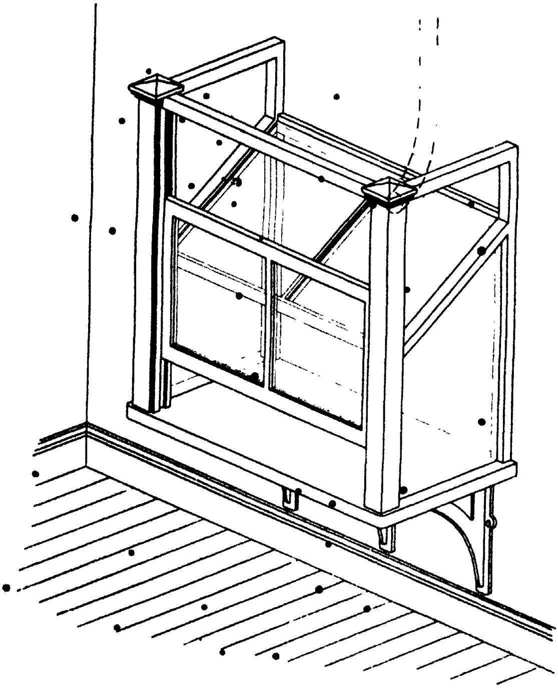


FIG. 13.—LARGE DRAUGHT-CLOSET.

on the same considerations as those described when determining the height of the bench-top (page 23).

The cubic capacity of the draught-closet should be kept as small as is consistent with sufficient space for

manipulating the apparatus that may be placed in it; this is to allow the air inside to be changed as frequently as possible.

The best position for the mouth of the extract flue or pipe is near the top, which generally can be sloped so as to lead ascending currents of air towards the outlet. As the extract flues in draught-closets in front of windows can be only placed at the ends in the jambs, they cannot be so satisfactorily ventilated.

The front of the closet is usually enclosed by a lifting sash, which is glazed and counter-weighted. The pulleys used should be as large as possible, in order that the sash may run easily; friction rollers are also sometimes used. As sash-lines do not last long, owing to the acid fumes in the atmosphere,* the front is often in the form of a glazed door hinged at the side, but its projection outwards when open is very inconvenient; this may be somewhat obviated by having a pair of doors. Various devices have been tried for opening and closing the sash or door, but the employment of springs and metal (except gunmetal) should be avoided as far as possible. The sash must be easily raised or lowered with one hand, as the student is often carrying apparatus in the other one.

The cords and weights are frequently concealed, but their condition is then not readily ascertained. To avoid this, the weights may slide up and down a wire fixed against the post,† or the cords or chains may pass over two pulleys, one of which is fixed above the sash and the other on the back-wall.‡

* Austin's patent "extra-fine twine sash-line" is a particularly reliable one. The life of sash-lines has been very greatly extended by thorough oiling; lard oil is, perhaps, the safest to use.

† As at Birmingham Technical School.

‡ As at Manchester School of Technology.

Instead of cords and weights, a balanced catch, such as the one shown in **Figure 14**, may be used. It should be a thick piece of lignum vitæ or greenheart working in a hardwood rack.

A counterbalanced sash can be generally raised or lowered by pressing on the top or bottom rails. One or two brass "sash-lifts" are, however, sometimes fixed on the lower rail, but as metal soon gets acted on, turned wood knobs are preferable.

If there is a door to the draught-closet, it is convenient to have below it a flap about 6 in. high, hinged at the bottom and kept shut by a button at either end.* This flap often affords sufficient access to the interior, for instance, to remove a Bunsen from under a flask, without allowing a large quantity of the fumes to escape into the laboratory, as the opening of the door would probably do. The height of the opening should be not less than 2 ft., so as to allow a retort-stand, for instance, to pass without being tilted.

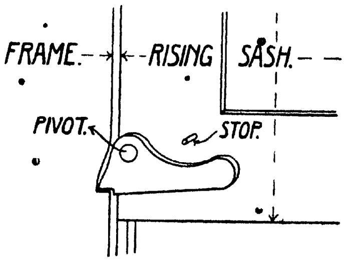


FIG. 14.—BALANCED CATCH.

The bottom or bed of a draught-closet requires to be made of a very carefully selected material; it has to resist the action of various chemicals and fumes and to withstand considerable heat from gas-burners and hot vessels. Stone, slate, lead, glass and iron have all been used for this purpose. Stone must be of a

* As at Addey and Stanhope School, New Cross.

non-absorbent nature without tendency to flake; there are Yorkshire flagstones and other compact sandstones which will meet the requirements. Slate can be used in thinner slabs than stone, but cracks unexpectedly with the heat; otherwise, it is a satisfactory material. Lead, after a time, has a dirty appearance, and the surface is liable to become uneven. Plate-glass is expensive, and easily cracked when heated unequally; the underside should be painted white, and the projecting edges protected by a wood ledge.

The other materials used in the construction of the draught-closet must be selected from those which are unacted upon by chemical fumes. The top and sides should be glazed, so as to admit plenty of light into the interior. The frame and sash or door can be in pitch-pine, red deal, American whitewood, oak, etc.

The back and other portions against the wall may be finished in various ways, such as with glazed bricks or tiles, slate, plate-glass, teak, or even iron. If iron or wood is used a protective coating is required. When the draught-closet is well-lighted, a varnish of a tarry nature, such as Brunswick-black, is best employed; but when it is not well-lighted, a white surface can be obtained by the use of paint, the finishing coats being of zinc white.

Glass, on account of its transparency, is, perhaps, the best material to use for the roof. It is important that the roof and extract flue are arranged so that no moisture due to condensation, or dirt, will fall into apparatus placed in the draught-closet. The draught must be rapid and sure.

If the outlet can be formed high up at the back, as previously suggested, it can be either circular or square in shape, a bell-mouth being, however, the best form.

When a direct opening from the top of the closet nto the extract flue is not possible, resort may be had to a false back: this is a sloping piece of wood, glass,

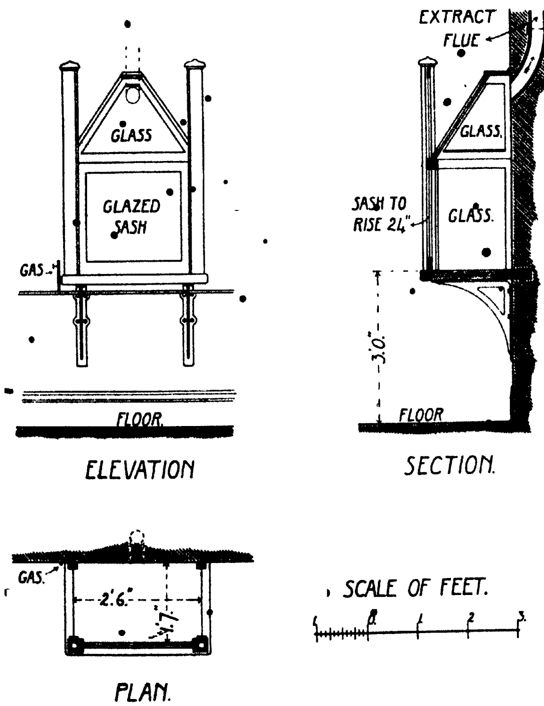



FIG. 15.—SMALL DRAUGHT-CLOSET.

or iron extending to within a few inches of the top of the draught-closet. In this way a trumpet-shaped flue can be formed, which has an aperture, the width of

which is determined by experiment, extending the whole length of the closet. Sometimes it is convenient to have an extra outlet at a lower level. This can be a horizontal slit in the false back, at about 12 in. above the closet-bottom, and fitted with a sliding cover.

The extract flue should be as straight as possible, and, if practicable, formed in the thickness of the wall. The friction in it must be reduced to its smallest limits (see "Ventilation," page 131); for this reason, circular glazed stoneware pipes or cement-rendered flues with rounded angles are good. The expense of glazed bricks or tiles generally renders their use prohibitive; if ordinary bricks are used, they must be smooth-faced and carefully pointed. As a rule, it is only during the construction of the walls that the flues can be concealed in them. When the flues are on the wall-face they may be of galvanised iron or steel, asbestos, wood or stoneware. Sheet-iron is rapidly eaten into by the acid fumes unless kept very thoroughly painted or tarred inside and out; galvanised sheet-steel pipes treated with two coats of Dr. Angus Smith's mixture has been found very satisfactory. Asbestos is practically everlasting, and strips of millboard, say $\frac{1}{8}$ in. thick, can be easily bent to any desired shape if soaked for a few minutes in water (see Appendix C.). Wood needs to be very thoroughly seasoned and in narrow widths, smooth inside, and with canvas glued on the outside. Stoneware pipes are clumsy and unsightly if used inside a building.

Where there are several draught-closets contiguous, they can either have separate flues or be each connected to a continuous one; the former is the more sure method if the draught is only actuated by a gas-jet burning in the flue.

There are several methods of obtaining the required aspiration :—

(*a*) Each flue or group of flues may be carried directly upwards into the outer air and have a lighted gas-jet at the bottom.

(*b*) The flues may be one or more series of branches which connect with a main flue at the mouth of which is a blower or fan (see "Ventilation," page 128) rotated by a steam, oil, or gas engine, electric motor or water power.

(*c*) The flues may be taken into a high chimney at the base of which is a furnace.

These three methods, where the draught is created by the gas-burner, the fan and the furnace respectively, are referred to in detail on pages 125 to 130. The first is somewhat wasteful and irregular in action; the second is simple, reliable, and economical; while the third is inconvenient, at any rate in the summer, if the furnace is only used to work the heating apparatus.

The velocity of the extraction of air should be such that the whole of the air in the draught-closet is completely changed at least three times a minute: twice this speed should be obtained, if possible, as the force of a moderate draught is not appreciable except close to the aperture. It is extremely important that the general extraction of the air of the laboratory is arranged so that it does not pull against the exhausts of the draught-closets. When the building is ventilated on the "plenum" system, all back-draught from the closet is rendered improbable, owing to the atmosphere of the laboratory being at a slightly increased pressure. With other systems of ventilation down-draught is sometimes experienced,* and the only satisfactory cure may be to introduce a separate air supply. If fresh air

* This was formerly the case at "Queen's College for Female Education," in Harley Street.

is introduced to take the place of the air which is being extracted from the closet, it must be brought in near the front; this ensures the movement of the air within the draught-closet being entirely in one direction, namely, from front to back. Generally it is sufficient to admit air, as required, from the laboratory by slightly raising the sash; as the opening then formed is a long narrow one, probably little or no deflection of the flame of a Bunsen-burner inside the closet will occur. When the sash is raised in this way, if the draught is reasonably strong, no serious quantity of fumes will escape through the space formed at the back of the glass of the sash. A strip of rubber or felt can be at any time fixed to the closet frame, so that it bears against the glass and closes this opening.

In a paper,* prepared by the late Mr. Ashwell and revised by Mr. Nesbit, there appeared the following description of the draught-closets at the Massachusetts Institute of Technology at Boston:—

"Within the hood is an inclined diaphragm of such width and placing as to leave a slot 3 in. wide along the whole front of the hood. Its location and inclination serve to protect the hood contents from injury by the falling of *debris* from the flue. The hood sash is prevented by stops from being raised beyond a fixed point, such that its lower edge shall be, according to the height and temperature of the hood, from 4 to 8 in. below the outer edge of the diaphragm. The space between the glass of the sash and the face of the hood is cut off from the hood space by the raised sash, so preventing escape into the room of gases, etc., by that means. The use of the diaphragm is apparent in

* Read before the American Society of Heating and Ventilating Engineers in January, 1898; see "Domestic Engineering" for March, 1898.

extending and equalising the current along the entire length of the hood. The direction of inclination given to it and the front location of the slot may not, however, be so apparently reasonable. The aim in the latter arrangement is to concentrate the discharge current along the line of most natural escape of warmed gases from the hood into the room, since all gases to escape must pass this line, which would not be true of a similar slot at the rear of the hood. The inclination given to the diaphragm is slightly upward from rear to front, that the initial upward movement may not be completely and abruptly broken, so forming a deep stratum of fumes which might then escape at the lower part, because beyond the reach of the effective action of the discharge current, or else might cool and settle or be forced down along the rear walls at a point remote from the heating burner, and so escape."

As iron pipes are rapidly corroded by acid fumes, all fittings for the supply of gas and water should be kept outside the draught-closets. If they must be continued inside, they should be of pure tin or tinned copper. If these materials are considered to be too expensive, there are porcelain-enamelled burners, which are better than unprotected ones, and pipes treated with Angus Smith's mixture. The taps ought all to be outside the closets, they can be of gun-metal oxidised and lacquered, or of iron black-enamelled (see page 39).

The gas and water, however, can be generally brought in as required, by means of rubber-tubing passed through holes provided for this purpose in the sides or bottom of the closet. Gas should be available for use in all draught-closets, while water should be laid on to one or more, preferably to the larger ones, if they vary in size. A waste-pipe must be provided when water is supplied; then the bottom of the closet should be sloped to the

outlet, or there should be a chase cut round the edge leading to the outlet. The waste-pipe must be trapped so as to prevent air passing through it.

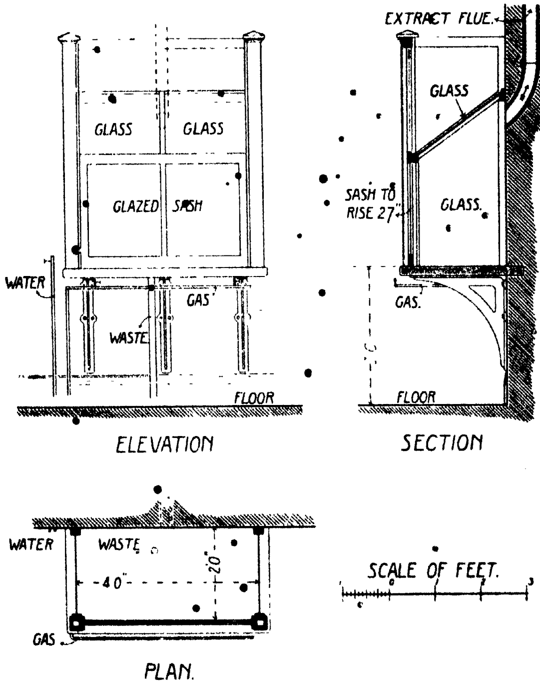



FIG. 16.—LARGE DRAUGHT-CLOSET.

A small sink let into the bottom of one of the draught-closets* is often found to be a great convenience; it

* As at Bedford College, London.

is particularly useful when apparatus or bottles, the contents of which smell objectionable, have to be washed out.

**Draught-closets for Special Purposes. Sulphuretted-hydrogen Closets.**—It is unnecessary usually to devote a separate room to sulphuretted-hydrogen work, or even to screen off a portion of the main laboratory for this purpose.

Apparatus generating sulphuretted-hydrogen gas is almost always set up in the laboratory for the use of the students.

Although such apparatus has been recently very much improved,* it is still advisable it should be placed in a suitable draught-closet. It must be remembered that not only may a student inadvertently omit to turn off the supply-cock, but a little of the gas may be allowed to escape when the apparatus is being used.

In small laboratories, it is sufficient to provide a sulphuretted-hydrogen draught-closet about 2 ft. 6 in. long by 1 ft. 7 in. from front to back inside.

In case of accidents, it is advisable to fit a waste-pipe to this closet. When it becomes necessary to wash out the Kipp or generating apparatus, it can be either closed and carried into the open air, or the spent acid can be emptied out in the draught-closet. If the latter practice is followed, a lead-lined tray, about 2 in. deep, can be formed on the bottom of the closet †; water supply and waste pipes are then required. If cylinders of liquid sulphuretted-hydrogen are used, the unpleasant process of cleansing the apparatus is avoided.

If the number and distribution of the students in the laboratory render it advisable, two or more

* By Dr. F. M. Perkin.

† As at Aston Technical School, Birmingham.

draught-closets, each containing a separate sulphuretted-hydrogen apparatus may be fitted up in different parts of the room.*

Where a considerable quantity of the gas is required, a suitable position for the generator should be found outside the laboratory, and a supply of sulphuretted-hydrogen laid on to a series of small glazed wooden chambers, each about 8 in. long, 10 in. from front to back inside, and 14 in. high. The gas is conducted from the generating apparatus, or gas-holder, by a copper or lead pipe, which is run just above the compartments, and branch-pipes fitted with stop-cocks are taken down into each one. The branches project about 2 in. below the tops of the chambers, and have a short piece of rubber-tubing on the end of them. Each time a student wishes to draw off some of the gas he attaches a suitable length of clean glass-tubing. In case the students accidentally upset or break the test-tubes or beakers they are using, each compartment should be drained. This is best done by means of a loose glazed tile perforated with a number of small holes, which communicate with a continuous lead-lined trough, laid to a fall, beneath the chambers, and fitted with a trapped waste-pipe. It is essential all the chambers should be connected with an extract flue, which can be either at the back or below: in the latter case, it will carry off not only all sulphuretted-hydrogen gas that escapes, but also the liquids that may be spilt from time to time. As the chambers are very small, and consecutive ones are not often in use at the same moment, glazed doors and not lifting sashes are generally fitted. One or more larger additional chambers should be

* It is usual to allow one apparatus to about every ten or twelve students that can be accommodated in the laboratory; the demand for the gas, however, varies considerably with the nature of the work carried on.

provided, as it is sometimes necessary the solution, into which the sulphuretted-hydrogen gas is to be passed, should be heated. A drained draught-closet, 2 ft. 5 in. long, 1 ft. 5 in. from front to back inside, and 2 ft. high, with the coal-gas supply-pipe close at hand and the sulphuretted-hydrogen gas-pipe brought inside, would meet the requirements.

The flues from all sulphuretted-hydrogen closets are better kept distinct from those in connection with other fittings, and, where possible, should be taken direct into the boiler flue. If it is inconvenient to avoid connecting up the sulphuretted-hydrogen flues with the other flues in the laboratory, they should, at any rate, join the main flue, where the draught is most powerful and reliable.

**Evaporation-closets.**—Evaporations are frequent chiefly in quantitative work, and are carried out by means of water or sand baths, or by water or air ovens. These are used according to the nature of the substances operated upon, the speed at which the drying is to be conducted, or the limit of temperature which is not to be exceeded. On a small scale, it may be sufficient to make use of the portable water-baths supplied by apparatus makers; they are heated by gas-burners, but without constant attention the water is apt to boil away.

If acid or other fumes are driven off, the operation has to be conducted in a draught-closet. For evaporations, or the concentration of solutions, which occupy much time, it is inconvenient to use the ordinary draught-closets, and therefore special ones are often provided for evaporating purposes only.

Where steam is available, it should be employed in the special evaporation-closets. The following description is based on the fittings devised by Dr. Thorpe for the

Yorkshire College, Leeds, the Government Laboratory,

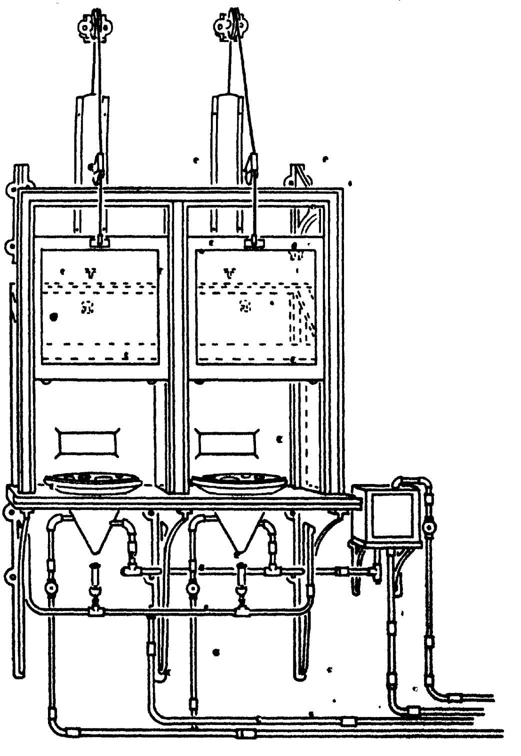


FIG. 17.*—EVAPORATION-CLOSETS.

London, and the Manchester Municipal School of

* Figures 17, 18, and 19 are reproduced, with permission, from the catalogue of Messrs. Brown & Son, of Charlotte Street, N.

Technology. The closets are generally divided into compartments about 19 in. square inside. The bottom is a slab of stone or slate, into which is sunk in each compartment a loose porcelain or fireclay collar over a copper cone or pan. On the collar is placed a disk of heat- and acid-resisting material, having circular apertures of diameters varying from 2 in. to 4 in. for the reception of the evaporating-basins; loose covers are provided for these holes; uralite is very suitable for these disks. A steam-pipe is connected to the conical copper vessel, and another pipe fixed at a slightly lower level carries away condensed steam. In case the steam-supply fails, Bunsen-burners should be fixed below the pans, which must be connected with the water-supply so as to maintain a constant level. The front of the slab is finished with a wooden shelf about 6 in. wide; this affords a convenient surface on which the hot basins can be put down. The front has lifting sashes or doors like the ordinary draught-closet. The compartments are separated by glass partitions, which should be very thin in case a jet of steam should strike against them. The extract flue should be a long low opening, slightly above the level of the evaporating liquid. As it is very important that no condensation should drop into the evaporating vessels, the roof of the draught-closet must be carefully arranged. It can be kept low and be formed of two sheets of plate-glass, the lower glass sloping down from the front to just above the flue opening, while the upper one slopes in the opposite direction and is easily removed for cleaning.

A *sand-bath* may be fitted up in one of the ordinary draught-closets, in a simple manner, by means of an iron plate on which the sand is heaped, a high-power atmospheric burner being placed underneath.* The

* As at the East London Technical College.

temperature obtainable can be varied by using plates of different thicknesses, and by selecting a suitable position on the plate relative to the source of heat. The disadvantage, however, of a shallow sand-bath is that with large basins, owing to the curvature of surface, only a small portion of the bottom is exposed to the heat. Electrically-heated plates are generally too expensive to be seriously considered.

A store of *distilled water* is essential for all chemical work. It is usually preferred to distil the water in the laboratory, so that its freedom from impurities is assured, and the stock renewed as fast as it is used. The process consists in condensing steam in a block-tin worm, surrounded by a constant current of cold water. The distillation of water may be combined with the heating of drying-ovens or water-baths. The steam, if free from oil and other impurities, may be obtained from the boiler installed for heating, ventilating, or lighting the building, or else from either a copper still in the laboratory, or from the drying water-ovens or water-baths. Exhaust steam from machinery usually has a considerable quantity of oil from the cylinders, etc., mixed with it; a large proportion of this oil can be, however, removed by using an oil separator which contains a number of baffle plates. On the other hand, steam from a steam-turbine is free from oil.

If steam is laid on to the laboratory, it can be employed in the following manner for heating drying-ovens and sand-baths, and for obtaining both hot and cold distilled water.* The drying-oven is a strong copper box having an outer copper jacket, surrounded,

* This connected system, devised by Dr. Thorpe, is fitted up throughout the Government Laboratory, and its success induced him to recommend its adoption at the Manchester Municipal School of Technology.

except in front where the doors are, by an oak or mahogany casing and asbestos packing. A convenient

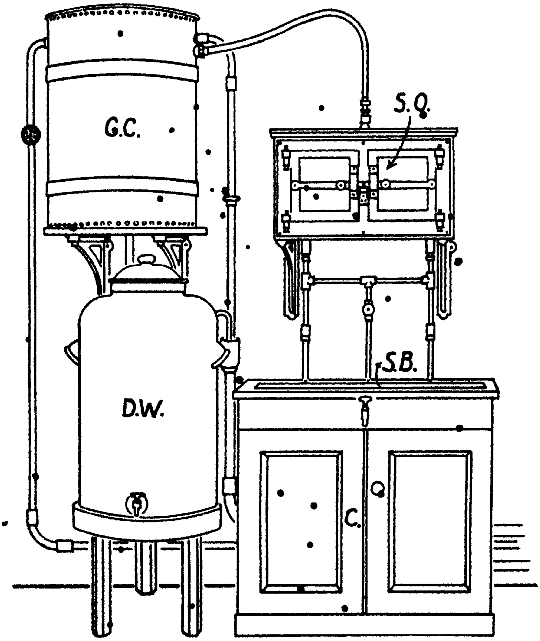



FIG. 18.—CONNECTED SYSTEM OF STEAM-OVEN (S.O.), SAND-BATH (S.B.), COOLING CYLINDER (C.C.), DISTILLED WATER STORE (D.W.), AND DRYING CUPBOARD (C.), WHERE SUPPLY OF STEAM IS AVAILABLE

size is about 19 in. long, 7 in. from front to back, and 9 in. high inside; a loose shelf about $2\frac{1}{4}$ in. wide pierced with suitable slots to retain funnels and tubes in an

upright position, may be fitted inside. The doors are either double, or of gun-metal, with plate-glass panels. The oven is carried on brackets, which are fixed against the wall about 4 ft. from the floor. A regulated current of air is led into the interior by a pipe, which is taken through a considerable amount of the heated packing; it enters and leaves the oven at the bottom and top respectively by orifices as far apart as possible. The steam enveloping the ovens enters from below by pipes which, if branched downwards, can be used to convey any condensed steam into a tin-lined copper box. This box is fitted with an overflow pipe and steam-trap, and also with a tap by which hot distilled-water can be drawn off. It can be conveniently about 30 in. long, 12 in. wide, 3 in. high, and 30 in. above the floor. If the sides are carried up to form a shallow tray, it can be used as a sand-bath, while a drying-cupboard for dusters, etc., can be constructed underneath. The waste-steam from the drying-ovens is led through a pure tin worm, coiled in a galvanised iron cooling cylinder about 24 in. high, and 18 in. diameter; through the latter a continuous current of cold water passes in an upward direction. The worm must, in every part, slope downwards, and be kept in shape by a light metal stand. The condense water dropping from the worm is most suitably stored in a large stoneware jar, fitted with a glass or stoneware draw-off tap, not less than 1 ft. 6 in. above the floor. The level of the water inside can be rendered visible by taking a strong glass overflow-pipe up from the bottom.

When the steam is obtained from a laboratory still, water-oven or water-bath, instead of from the boiler, the waste-water from the condensing drum can be partially utilised for maintaining a constant level in the still, or the outer casing of the oven or bath.

**Combustion-bench.**—If there is no Combustion Room, it will be necessary to provide a shelf or shelves

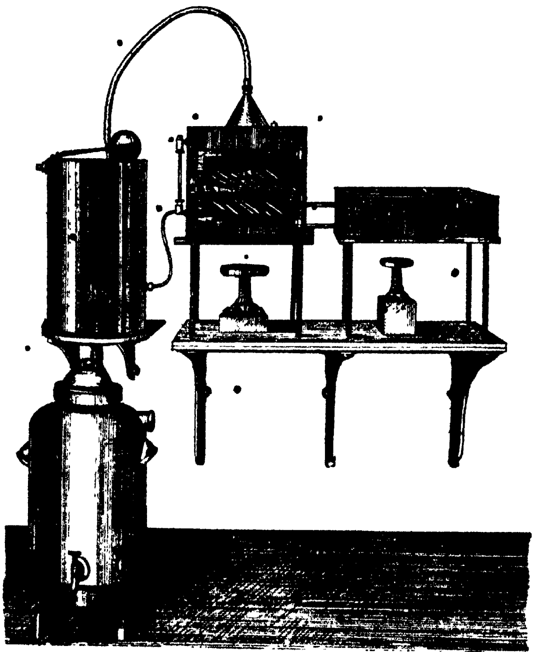


FIG. 19.—WATER OVEN AND BATH, STILL AND CONDENSER, ETC., WHERE NO SUPPLY OF STEAM IS AVAILABLE.

on which combustions can be conducted. Unless this is placed against the wall, it is difficult to provide a hood and extract flue to get rid of the heated air, etc. The material and size of this bench will be referred to

later, when discussing the fittings of the combustion-room (see page 75, and fig. 22). It can be as long as possible, because, besides the furnaces, various appliances such as small water baths and ovens, etc., may be conveniently placed here.

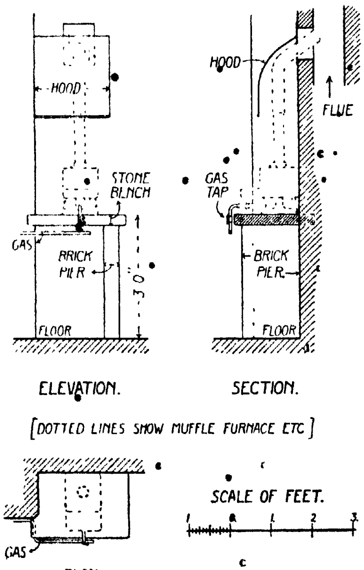



FIG. 20.—MUFFLE FURNACE BENCH.

A gas-pipe of ample size should be taken along the bench at the back. For some purposes it is convenient to have water also laid on; this pipe is best fixed against the wall above the gas-pipe. To carry off any waste-water a half-round channel should be formed near the back of the bench; this can be generally arranged to deliver into a sink at the end.

**Blowpipe Table.**—One or more tables reserved for blowpipe work are sometimes placed in the laboratory. A convenient width is 2 ft., but the length may vary from 2 ft. 6 in. to 4 ft. or more, according to circumstances. The top is covered with lead or zinc, which is dressed over a fillet standing up an inch or two all

round the edge of the table. When only mouth-blowpipes are used, it is best to sit to the work and the table-top should be about 2 ft. 9 in. above the floor. For long continued ignitions, an air-blast obtained by high-pressure water-supply or by foot bellows is used; it is then more convenient to stand and the table-top should be about 3 ft. 3 in. high. As a plentiful supply of gas is required for this work, it is better to have a large pipe permanently brought up to the level of the table-top and the table fixed to the floor, rather than have the table portable, and rely on obtaining gas from the nearest point.

**Glass-blower's Table.**—This is not an essential fitting, as glass-blowing can be done at the blowpipe table, if luminous burners are provided. Occasionally one such burner is fitted at each bench-place for glass-bending. The tables supplied by apparatus makers usually vary in size from 24 in. by 18 in. to about 30 in. by 24 in.; the zinc-covered tops have a notched raised edge.

Sometimes regular instruction is given to the students in the art of glass-blowing, in which case it is better to set aside a suitably-fitted room for the classes.

**Reagent-shelves.**—In addition to the reagents usually provided on the working-benches, there are a considerable number which the students need for their work and to which they require ready access. These should be placed as far as possible on shelves against the walls. The shelves should be from 5 in. to 7 in. wide, with a height of from 7 in. to 10 in. in the clear, between them. In some laboratories, if the floor-space can be spared, it is advisable to have, in the centre of the room, one or more bottle-stands for these reagents

and chemicals. Each stand should be from 4 ft. to 10 ft. long, and about 1 ft. 10 in. wide, with a central division down the middle, and a row of bottles on either side on several tiers of shelves.

The question of a suitable material for the shelves has already been gone into, when referring to the shelves on the working-benches. The brackets supporting these shelves can be either of wood or metal. When wood is employed, the brackets, having to be rather wide and deep so that the shelves are perfectly rigid, may interfere with a bottle placed on the shelf immediately beneath; on the other hand, metal brackets can be smaller, but bottles are more likely to be cracked or broken by accidental contact with them.

**Large Sink.**—A large sink must be provided in the laboratory for the washing of apparatus and bottles. Possibly a convenient corner can be found where it will not be very conspicuous and yet be sufficiently accessible. A strong cream glazed stoneware sink, about 28 in. by 18 in. by 6 in. deep inside, would meet the requirements, if it is supplemented by a draining-board of grooved teak about 2 ft. long. It is convenient to have both hot and cold water laid on. The height of the water-taps above the sink requires careful adjustment to the circumstances, as it may be found some of the apparatus, such as condensers, to be cleansed is of considerable size or length. A height of 24 in. above the bottom of the sink will be probably found advisable. The top of the sink should be about 2 ft. 9 in. above the floor.

**Filter-pumps.**—At convenient places in the laboratory, there should be water-taps, to which filter-pumps can be attached, and also some means for getting rid

of the waste-water. A pressure equal to 4 or 5 in. of mercury is generally sufficient. If a considerable head of water is not available, a fall of some 10 or 20 ft. must be obtained; for this a very small pipe will suffice.

**Demonstrator's Table.**—The material and general design of the demonstrator's table should be similar to

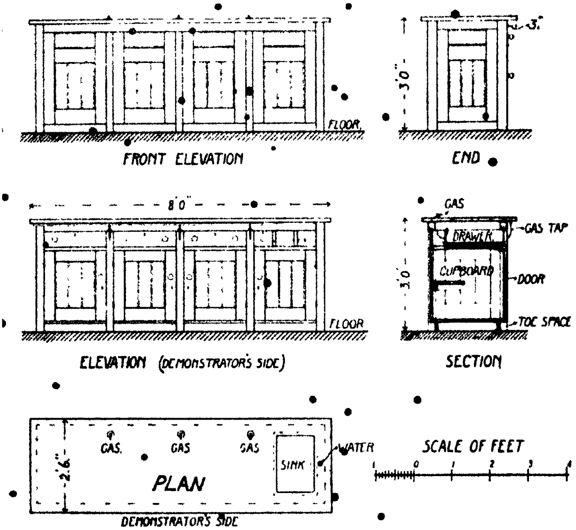



FIG. 21.—DEMONSTRATOR'S TABLE.

the working-benches. The size has been already referred to (page 15). At the back beneath the top, which is usually of teak and 3 ft. high, is a series of drawers with cupboards and recesses below; the recesses are similar to the cupboards with the omission of the doors. A continuous toe-space should be formed

at the floor-level. A sink about 18 in. by 12 in. and 6 in. deep is useful. Over the sink is a water-supply standard of sufficient height, say, about 18 in., to enable large vessels to be put under the tap. There are seldom either reagent-shelves or draught-closets actually on the table itself; if they are provided, they must be kept low and only placed at the ends, so as not to interfere with the supervision of the laboratory. The gas-fittings can be arranged like those on the working-benches; there should be two or three nozzles at intervals along the table. A pneumatic trough is not often required; if constructed, it can be about 27 in. by 19 in. by 16 in. deep, with glass front and back, and means of illuminating artificially at the back. For emptying the trough a waste-pipe connected to the drains is necessary, and, if possible, water should be laid on to it. It is convenient to have a hinged or sliding flush cover of wood to the sink and pneumatic trough.

**"Black-board."** — A "black-board" must be arranged for somewhere in the laboratory, preferably against the wall. It should be, if possible, in close proximity to the demonstrator's table or the bench at which he works. It is desirable that there should be, in front of the board, a clear floor-space where students can stand and obtain an uninterrupted view of it.

Various materials have been used, such as wood, slate, glass and cloth: all these, with the exception of slate, require a specially prepared black or dark green surface. A grooved ledge or shelf, about 2½ in. wide, fixed along the bottom edge of the black-board, is useful for catching the chalk dust, and for holding the chalk-sticks.

If the "black-board," instead of being fixed, slides

up and down in a frame, pitch-pine, Darlington slate-board or American pine, are the most suitable materials; it can be counter-weighted by a cord and weight at each end, or by a continuous cord and one weight on the Kelvin-suspension principle.

When the black-board is fixed, the bottom edge should be about 3 ft. 6 in. above the floor. As chemical equations require considerable length of space, it should be not less than 5 ft. 6 in. long and about 3 ft. 3 in. high.

Where the wall-space is limited, there can be two boards, arranged so that one slides in front of the other, or both sides of one board can be utilised by providing, along the top and bottom edges, projecting metal tongues, which slide horizontally into grooved blocks fixed to the wall. Double boards can be formed either by hinging them down the middle so that the two parts move like the leaves of a book, or by providing side wings which fold over the central portion.

**Dispensary.**—A dispensary or store for the more expensive and less frequently-used chemicals is useful.* It can be conveniently a small space partitioned off either at the side or in the centre of the laboratory, according to circumstances. This space must be not less than 4 ft. 6 in. wide and from 8 ft. to 10 ft. long. Inside, it is fitted with shelves 5 in. and 7 in. wide, 12 in. apart, the lowest shelf being about 1 ft. 6 in. above the floor so as to allow sufficient height for a row of Winchester quart bottles. It is convenient if the demonstrator can retire here and make up test-solutions out of sight of the students; therefore a door is advisable, but the partitions need not be more than 6 ft. high

* There are examples at Yorkshire College, Leeds, and other laboratories.

or somewhat less if there is a shelf for bottles along the top. There need be no roof to the enclosure. For preparing the solutions, it is advantageous to have a short bench fitted with small sink, drawers and cupboards; gas and water should be provided, if possible. Against the outside of the screens may be placed glazed cupboards for glass apparatus, such as burettes, pipettes, hydrogen apparatus, nitrometers, etc., required by the students from time to time; they should have movable shelves 7 in. wide and about 2 ft. 10 in. long.

**Key Cupboard and Notice Board.**—If the students are provided with a key for their bench cupboards and drawers, and are instructed not to take them out of the laboratory, a key-board should be fixed against the wall in a convenient position. It should be under the control of the demonstrator, and will serve also as an attendance indicator.

The board should be divided up into spaces about 3 in. high and 2 in. wide; at the top of each space is a hook and a number corresponding to that on the bench-cupboard. For safety it may be enclosed within a shallow glazed cupboard, of which the demonstrator retains the key. Near this key-board it is convenient to have a notice-board, which may be covered with a sheet of compressed cork, a material preferable to the more usual green baize.

**Glass-tubing Stand, etc.**—A stock of glass-tubing, where a separate supply is not allotted to each student, is frequently kept somewhere in the laboratory so as to be readily accessible. If it is stored on a special shelf with a raised fillet along the front edge, it is somewhat difficult to select a particular tube from amongst a large number. Hence it may be preferred to keep the

tubing, or at any rate the long lengths, in a stand which is perhaps best described as a tall umbrella-stand. The top, which should be not less than 2 ft. 9 in. from the floor, may be merely divided into compartments about 5 in. or 6 in. square, or it may carry a board pierced with a number of holes 3 in. or 4 in. in diameter.

**Stools.**—In many laboratories there are not stools at every working-place. In some cases, this is due to the belief that students, especially elementary ones, are more likely to get on with their work if they have to stand. Of course, for some work, such as that with the mouth-blowpipe, it is necessary to sit down. Of course, students who are at work for three or four hours at a time must be provided with stools.

The stools should be strongly framed together, with a wood seat about 12 in. by 10 in., 24 in. or 26 in. high. Similar stools can be used in the balance-room. In girls' schools, where the furniture is not subject to such rough treatment as in boys' schools, some slight extra comfort can be given by providing a low back to the stools.

**Windows, Skylights, etc.**—It is often advantageous to have both windows in the walls and skylights in the ceiling. A horizontal light is convenient for examining the contents of, or action going on in, a flask or test-tube, while a vertical light admits of the better inspection of the contents of a crucible or water-bath.

Skylights, if used, should not face the south, as the laboratory would then become inconveniently hot in summer. A ridge-and-furrow roof with the glass-slopes inclined at 60 degrees with the horizon,* and facing

* As at the Institute of Chemistry, Bloomsbury Square.

north or east, is an excellent arrangement, except that snow is very liable to accumulate on it in large quantities; this disadvantage can be somewhat overcome if waste-steam is available, by carrying a steam-pipe, perforated with holes, along each gutter.

No coloured glass should be used in any of the windows. Great care should be taken to make all the skylights water-tight and air-tight so as to prevent the entrance of rain and blacks. The advantage of being able to very rapidly change the air of the laboratory or lecture-room, by means of the windows, is fully appreciated when, by accident or otherwise, a large volume of unpleasant fumes has been formed. Therefore all windows should be made to open, and open widely, even though an artificial method of ventilation may be employed throughout the building.

An unusually wide stone sill outside some or all of the windows is often a convenience, as it allows apparatus giving off objectionable fumes or likely to explode, to be put there. It may even admit of work with ill-smelling or poisonous gases being carried on in the open air. Where there is no bench or other fitting in front of the window, the window-board should be at such a height that it can be conveniently used as a shelf. The space between the window-board and the floor is usually wasted; this can be avoided by keeping the wall thin there, and fitting-up a cupboard or a series of shelves or pigeon-holes in the recess thus obtained.

**Walls.**—Walls finished inside with glazed bricks are undoubtedly the best. A cheaper treatment would be a salt-glazed dado with distempered plaster above. If the walls are built in common bricks and not plastered, they should be distempered or at least

lime-whited, in order to impart some appearance of comfort and cleanliness.

As there are several reliable "washable" distempers now made, the advantages of using paint instead of distemper are not so great as formerly. If paint is employed for the walls, it should be "flatted."

A smooth and durable surface of a glazed nature can be obtained by using Blundell's Petrifying Liquids. The walls can be then safely washed down with a damp cloth: in some instances, the benches and other woodwork have been treated in a similar manner instead of using paint and varnish.

No very strong colours should be used, as the effect may be bothering when examining a faintly-coloured liquid.

Formerly it was considered that rooms used only for teaching purposes ought to be "barrack-like," and that anything beyond the necessary furniture was an extravagance, besides tending to distract the student's attention from his work. In these more enlightened days, however, it is admitted that students benefit by spending their school hours in rooms where there is a little colour, some simple decoration and well-designed detail. By accustoming the eye to these little attractive refinements, the mind is undoubtedly elevated, and unless this decoration is carried too far, so as to give an air of almost ease and luxury instead of serious work, the additional outlay is small.

In the lecture-rooms, library, reading-room and balance-room, blank wall-spaces can be advantageously relieved, without in any way destroying the character of the room, by suitable and instructive pictures. Portraits of celebrated chemists and scientists, or enlarged photographs of appliances used in chemical processes and industries, especially local ones, can be usually procured for this purpose.

**Floors.**—Floors are now constructed of various materials, such as boarding on wood joists, or concrete covered with either wood-blocks, boarding, cement, tiles or stone flags.

When a material is being selected, it must be remembered that various pipes, which must be always accessible, will have to be run to and from the working-benches and other fittings.

Cement, tiles and stone form an incombustible floor which is readily cleansed, but it is cold to the feet and somewhat noisy: wood-blocks have exactly the opposite characteristics. Portable wood gratings in long lengths, formed of battens three-quarters of an inch apart, have been used for the students to stand on at the benches when the floor is tiled or of cement or stone, but they render the use of stools almost impossible.

Channels or chases for pipes in the floor should be water-tight, in case of leakages; in concrete floors they can be lined with bitumen about 1 in. thick, or with tarred cement.

As dirt collects in and cannot be dislodged from the square angle between the wall and the floor, it is better to round this angle by inserting wood or cement fillets or stoneware blocks, of suitable section.

### Balance-room.

The balance-shelves, as already mentioned, are best supported from the walls; they may be of wood, slate or concrete, carried on stone, wood or iron brackets firmly fixed into or against the wall. In order to prevent the transmission of vibration, each balance may stand on a separate shelf, of a length varying from 1 ft. 6 in. to 3 ft., according to the size of the balance. A convenient width for the shelf is found to be 1 ft. 7 in. It is the usual practice for the students to sit when

weighing, but if it is preferred they should stand, the shelf must be about 3 ft. 9 in. above the floor, instead of about 3 ft. The shelves are required to afford a clean, level and perfectly steady surface. Mahogany is one of the best woods to use.

It is a good practice to have a piece of plate-glass, about 8 in. wide, laid on a strip of green baize along the front of the shelf.* It affords a clean surface on which the article to be weighed may be placed, and there is also the possibility of one of the weights being accidentally dropped. It is generally advisable to fix a rounded fillet along the back of the shelf to prevent the small weights slipping down between the shelf and the wall.

For elementary work and rough determinations, simple balances sensitive to, say $\frac{1}{100}$th grm., may meet the requirements; these are often kept in the laboratory, and are not seriously damaged by the atmosphere when the knife-edges and planes are of agate and not steel. Their general appearance, however, will soon become so unsightly, that the students are not likely to treat them with the care they should do. If it is unavoidable to have one or more expensive balances in the laboratory, it is then generally worth while to supplement the case, in which the balance is usually enclosed, with an outer casing, in order to exclude fumes as far as practicable. Those acid fumes, which do find their way to the balance, can be, to some extent, absorbed by some lumps of lime kept in a small tray beside it. The outer enclosure must be glazed at the sides and top, and the front can be a glazed lifting sash.

Behind the balance the surface of the wall should be

* As at the Royal College of Science, South Kensington.

white, so as to be both clean and reflecting. When it is required to illuminate the balance artificially, and electricity is available, a portable standard connected to a wall-plug is very convenient. The lamp should be on an arm, so as not to interfere with the manipulations; while a reflector can be used to throw the light on the scale and keep it out of the students' eyes.

Besides chemical balances, such instruments as microscopes, spectroscopes, and polariscopes are often kept in this room: the two latter require the exclusion of light, when in use, by means of small curtains of black material.

A shelf for desiccators can be conveniently provided in the balance-room; this can be of wood fixed against the wall at a height of about 3 ft. As desiccator-covers are usually from about 5½ in. to 8 in. in diameter, the shelf should be not less than 9½ in. wide.

If the Balance-room is also used as a Reading-room and Library, such furniture as a table, chairs, and bookcases are required. As the current numbers of chemical periodicals are often set out on it, the table can be, with advantage, considerably wider than one required merely for reading and writing purposes, a width from 4 ft. 6 in. to 6 ft. being advisable. Occasionally a special table is also provided, on which diagrams can be prepared. This table-top must be of considerable area, about 6 ft. by 4 ft. or 10 ft. by 6 ft., and it is convenient if it is adjustable to any angle; the space beneath can be sometimes utilised as a diagram-chest.

## COMBUSTION-ROOM.

A general description of the benches, with which this room would be fitted, has been already given when referring to the combustion-bench in the main laboratory.

Stone is the most satisfactory material for the benches; they can be, however, formed of concrete, if preferred. The behaviour of slate under the influence of heat is uncertain, and therefore it is better avoided. A wooden bench can be employed if it is covered with sheet-iron, and a suitable thickness of asbestos is introduced between the wood and the iron.

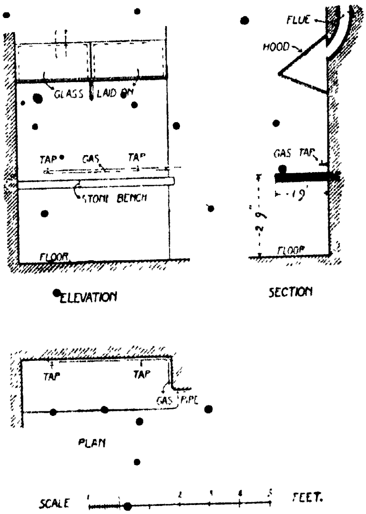



FIG. 22.—COMBUSTION-BENCH

The bench should be about 2 ft. 9 in. above the floor, as the student wants to look down into the furnace. The length and width of bench-space required varies very considerably with the kind of furnace used. A narrow bench is sufficient for a tube-furnace, but a considerable length is necessary to accommodate the furnace and any wash-bottles and apparatus that may be connected to it. A muffle-furnace, however, requires a wider bench but very little length. Therefore, the bench for each furnace varies from 1 ft. 3 in. to 1 ft. 9 in. in width, and from 2 ft. to 5 ft. in length, according to the nature of the work.

It has already been mentioned that it is advisable to

have a hood and extract flue over the bench to collect and get rid of the hot air and fumes from the furnaces. The hood can be of glass, sheet-iron, or slate, but all metal, in the form of a sheet-iron hood, or as a frame to carry the glass or slate, must be kept thoroughly coated with paint or Brunswick-black. It is better to avoid using wood, as it is apt to get charred.

For general combustion work, the hood should project from the wall quite as much as the bench below does, and the front, that is the lower edge of it, should be about 6 ft. above the floor. Sometimes there are glazed screens at the ends of the bench extending up to the hood.

Muffle-furnaces require a height of from 2 ft. 3 in. to 3 ft. 6 in. from bottom of burner to top of chimney. As the hood only has to enclose the flue-pipe, it probably need not project more than about 12 in. It may be found necessary to have an adjustable baffle-plate in the pipe if the draught is too powerful for the furnace.

The gas and water arrangements have been already mentioned in connection with the main laboratory combustion-bench.

### STORE-ROOM.

The shelves, bins, etc., for the apparatus and chemicals kept in stock vary so much in size and detail according to each individual article that it is impossible to describe them. The framing to carry the shelves should be kept as light as possible; instead of wood posts and rails, iron pipes of about 1 in. internal diameter may be substituted, if preferred.

If there is a desk where the storekeeper can keep his papers and do his writing, it can be either one of ordinary table height—2 ft. 7 in.—to sit at, or one 3 ft. 6 in. high to stand at; in either case the top should have the

usual slope of 15 degrees, and be about 4 ft. 6 in. long by 2 ft. 2 in. from front to back.

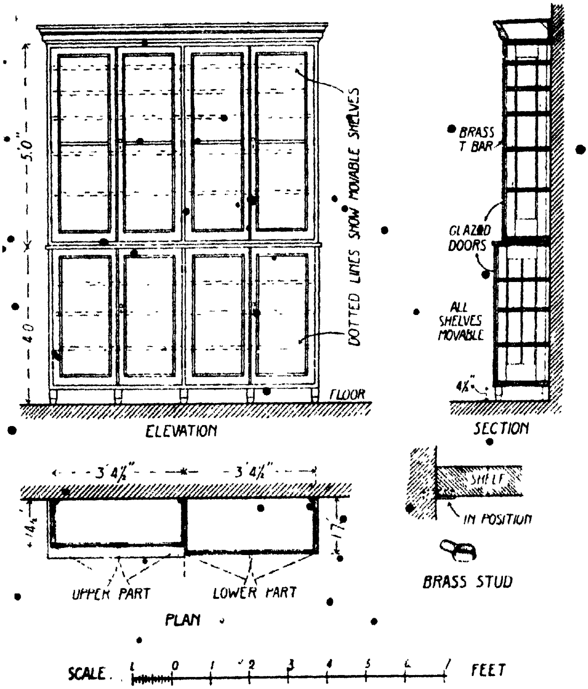



FIG. 23 —STORE CUPBOARD.

Among the other fittings which help to form a fully equipped store-room are a small working-bench and a large sink; both of these can be similar in detail to those described for the main laboratory.

When a counter is placed just inside the door, as mentioned in the general description of this room, it can be conveniently about 1 ft. 6 in. or 1 ft. 10 in. wide, and about 2 ft. 6 in. high, with shelves under, accessible only from the room-side. The shelf, also referred to, on the lower half of a divided door, need not be more than about 8 in. wide.

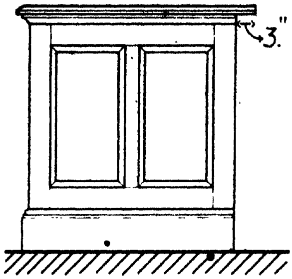
## LECTURE-ROOM.

The position, size, etc., of the *lecture-table* has been given in the general description of this room. Its length depends on the size of the room and other considerations. If possible, it should be 12 ft. or 14 ft. long; while for a large lecture theatre a table 20 ft. or 22 ft. in length may be required in order to have sufficient space to show all the apparatus and specimens necessary to fully illustrate a lecture. Three feet is a suitable height for the table. The table-top is usually made of teak, and the front and ends in pitch-pine.

Along the front, that is, facing the students, there is sometimes a series of shallow cupboards with glazed doors for the reception of specimens. Occasionally the doors are not glazed, and the cupboards are used for the storage of lecture apparatus; this would be only when cupboard and shelf accommodation is very limited.

At the back the space under the table-top is divided into a series of drawers, cupboards, and recesses of various sizes. The drawers are required for such articles as corks, tubing, filter-papers, and watch-glasses, the cupboards for flasks, bottles, cylinders, etc., and the recesses for retort-stands, tripods, wood blocks, etc.

The other fittings vary in number and kind with

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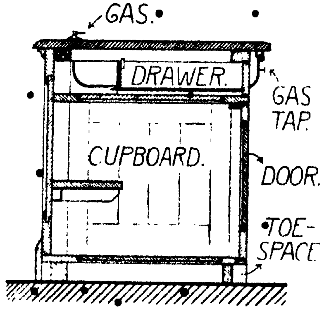


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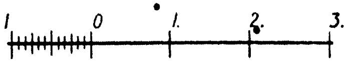


[To face page 78.

the particular conditions. Every lecture-table, however, ought to have some gas and water laid on, and a small sink with waste-pipe; while a down-draught flue brought through the table-top is a great convenience. The remarks regarding the position of gas taps and nozzles on the working-benches apply also to the lecture-table, along which there should be nozzles about 1 ft. 6 in. or 2 ft. apart. A large gas-tap near one end of the table is convenient for connecting to a combustion-furnace. The sink and water supply-pipe can be similar to those described for the demonstrator's table in the main laboratory; one or two small additional water-taps at other points on the table are often very convenient for connecting to condensers.

The down-draught flue is usually either a stoneware pipe or metal flue brought up at one or more points about half-way across the table; loose wood covers to close the openings, when not in use, are advisable. Experiments requiring to be conducted in a draught can be then made on the table in sight of the students: the apparatus is placed near one of these apertures, and covered with a sort of magnified balance-case, or a large funnel connected to the down-cast is supported over the apparatus.

It is better to keep the centre of the table clear for the lecturer's notes and papers. If preferred, a small reading-desk may be provided for him here; probably a sloping book-rest, about 18 in. long and 15 in. wide, will be sufficient.

A large pneumatic trough, as mentioned in connection with the demonstrator's table, is often provided in a lecture-table, but it is seldom used. A mercury trough, even if provided, is still more rarely used, owing to the portable trays now obtainable: it need not be so large as the pneumatic trough, about 18 in. by 14 in. by 1½ in.

deep* being sufficient for most experiments; the bottom should be slightly dished to a plugged outlet.

In some instances the lecture-table is not considered complete without supplies of electricity, steam, compressed air, etc.

In the general description of this room (page 18), reference was made to a *large draught-closet* constructed in the thickness of the back-wall; it is usually from 4 ft. 6 in. to 6 ft. long and about 2 ft. wide, the opening being about 3 ft. high and fully 3 ft. above the floor. The ends and tops should be preferably of white glazed bricks or tiles, with rising glazed sashes in front, and also at the back if it opens into the preparation-room. Occasionally the bottom is an iron tray or copper box with gas-burners in the space below, so as to form a hot closet;† this is usually done only in a large lecture theatre, and then a small draught-closet is often provided for more general purposes.

It is convenient to have a cupboard or series of *shelves* on the back-wall for reagents, placed so that they are readily accessible to the lecturer.

The reagents are in somewhat larger bottles than those for students' use, and therefore the shelves should be about 7 in. wide and 8 in. apart.

One or more "*black-boards*" are indispensable. The materials of which they can be constructed have already been enumerated in connection with the demonstrator's board in the main laboratory (page 66); the advisability of a considerable length of prepared surface was also pointed out. The surface of the black-board must be smooth and even, and of such a nature that it does not reflect the light, is easy to write on

* As at Chelsea Polytechnic.

† As at Owen's School (Boys), Islington.

without wearing down the chalk so rapidly that it is impossible to keep a point, and can be rapidly cleaned with a dry duster.

When the black-board is fixed, the position of the top edge is determined by the height, to which the lecturer can reach with comfort, when standing on the floor; the bottom edge is the lowest level at which he can conveniently write, or which the students sitting in their seats can see. These considerations generally give a board about 3 ft. 3 in. deep with the lower edge about 3 ft. 6 in. above the floor. As it is often inconvenient to be obliged, through want of space, to rub out writing or sketches previously made, the depth of the black-board is frequently increased beyond the above limits and it is constructed to move up and down vertically. This arrangement allows each lecturer to do all his writing at the particular height which suits him best.

The amount of surface can be still further increased by providing two suspended black-boards, one of which will pass down in front of the other. They can be arranged, if desired, to come down in front of the large draught-closet previously referred to. Some methods for rendering both sides of a black-board available for use have been already given (page 67).

As diagrams are frequently employed for lecture purposes, it is a great convenience to have a *diagram-screen*. This can be generally hung against the back-wall of the room at such a height that it does not interfere with the black-boards, etc., and yet admits of the diagrams being explained by means of a pointer of moderate length. The screen can be a light trellis frame with halved joints and openings about 6 in. square; if it is about 6 ft. 9 in. long by 4 ft. 9 in. high, it will take diagrams of double-elephant and antiquarian

sizes; these can be fastened on with drawing-pins or clips. If the diagrams are mounted on linen, it may be sufficient to pin them along the upper edge to a broad strip of wood and simply hang weights along the lower edge. As it is advisable to be able to raise and lower the frame or lath, they are best suspended near the ends by cords passing over pulleys, which should be not less than 4 in. in diameter.

A table of the Elements, their symbols and atomic weights is frequently painted on the back-wall, the area occupied varies, of course, somewhat with the size of the room; perhaps a space about 3 ft. by 5 ft. may be found sufficient. The Periodic Law is sometimes also shown in a similar way, the wall-surface occupied by this table will be probably about 5 ft. 6 in. by 4 ft.

For *lantern work* a suitable surface not less than 10 ft. from the lantern must be available, on which the pictures can be projected. A white roller-blind or screen is sometimes provided for this purpose, but more often a portion of wall-surface is whitened. The area required varies, according to circumstances, from about 6 ft. to 9 ft. square; it is generally advisable to ensure a smooth and reliable surface by using a cement, such as Keene's. The pictures are best seen when thrown on the back-wall, or on a screen either against the back-wall or across the angle of the room. It is, however, rather a serious disadvantage when a side-wall has to be utilised, although if the slides are principally diagrams, fore-shortening is not of very great consequence. If the lantern can be placed at one end of the lecture-table, it will be under the control of the lecturer.

The windows of the lecture-room are frequently fitted with *dark blinds*, although it may not be always

necessary to use them* when lantern slides are being shown. The edges of the blinds should slide in grooves not less than 3 in. deep. Almost any dark material can be used; as the probability of their getting out of the grooves, owing to draughts or other causes, depends chiefly on their stiffness, a thin material painted both sides is best. A spring-roller is generally employed, and it is fixed either along the top or bottom of the window, but there are conditions when the blinds are best drawn horizontally across windows or skylights. If a simple method can be devised, by which the dark-blind cords can be manipulated from a point near the lecture-table, so much the better.

As has been previously pointed out, the arrangement of the *seats* requires careful consideration. The rake of the seats should be a hollow curve and not a straight line, in order to ensure for each student an uninterrupted view of the experiments. The seats are generally from 2 ft. 3 in. to 2 ft. 8 in. from back to back.

To obtain the correct curve,† a diagram must be got out, after the plan of the lecture-room has been settled, that is to say, when the distance between the lecture-table and the first row of seats, and also the back-to-back spacing of the seats are known. The diagram must be to scale; it will be a section taken through the lecture-table and seats. First draw a series of vertical lines to represent the seat-backs. Then, from a point representing the middle of the lecture-table, draw a line to cut the back of the first seat at the level of the top of the student's head; continue it till it meets the back of the second seat; this will give the

* Except where only an oil lamp is available or when the sun shines.

† Scott Russell's method, see Roger Smith's "Acoustics of Public Buildings," page 42.

approximate position for the eyes of the second student. Then allowing a height of 6 in. to the top of his head, draw, from the lecture-table, another line to the top of the head of the second student, and continue it till it cuts the back of the third seat. Again measure 6 in. up, and so on for the remainder of the seats. Allowing heights of 16 in. to 18 in. from floor to seat, of 3 ft. to 3 ft. 6 in. from seat to top of student's head, the correct position of the seats and staging can be readily obtained. If the height of the desks above the seats is kept the same throughout, it will be found the

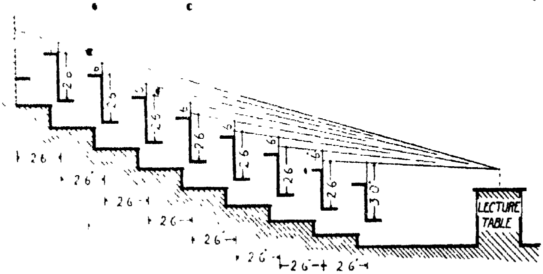


FIG. 25

backs of the seats are of variable heights. This will necessitate adjustable seats, if cast-iron standards are used to support the seats of one row and the desks of the next row behind. The length of seat usually allowed per student is from 18 in. to 24 in.; 2 ft. 6 in. or 3 ft. is sufficient width for gangways between seat-ends and the wall, and 2 ft. for those between the ends of seats in separate lengths. Care should be taken to make the rise of the gangway-stairs uniform throughout, if it is possible.

If each student has an uninterrupted line of sight of the lecture-table and the lecturer, there will then be

a direct path by which the *sound* of the lecturer's voice could reach him. Whether it actually does so, to a sufficiently audible degree, in a large lecture theatre, and whether the room is a good one to speak in, depend on various conditions, such as the shape and proportions of the room, the air-currents, the nature of the surface of the walls, floor, etc. If the room is very high for its width, there will be above the students a large mass of air, and to have to put this into vibration will cause the lecturer unnecessary exertion; besides it may have the effect of impairing the distinctness of his voice. A large amount of air above and behind the lecturer is, however, far more serious. It is advisable, especially in a room of considerable length, that the ventilation should be arranged so that the air-currents are in the direction the sound has to travel rather than towards the lecturer or across the room.

PREPARATION-ROOM.

The glazed cupboards for the storage of apparatus should be about 13 in. or 16 in. from front to back inside. The cupboard-doors are best hung on hinges in the usual manner; if they are made to slide, they do not, as a rule, work so well and are not so convenient.

The working-bench varies in length, according to the requirements and the available space; from 9 ft. to 12 ft. is often found to be a suitable allowance; it is not, however, necessarily a continuous one. The drawers, cupboards and gas-fittings can be similar to those in the main laboratory benches. It need not have a sink, if it is near the large sink, which latter is almost an essential fitting, and can be about 28 in. by 18 in. by 6 in. deep. About 2 ft. 6 in. above the sink

and draining-board may be fixed a draining-shelf, that is, a board pierced with holes from 1 in. to 3 in. in diameter, to receive the necks of flasks, retorts, etc. If hot water cannot be laid on to the sink, it is a good plan to have one of Fletcher-Russell's "instantaneous" water-heaters (see **Figure 26**). They take up very little space, only about 14 in. by 6 in. high; with these

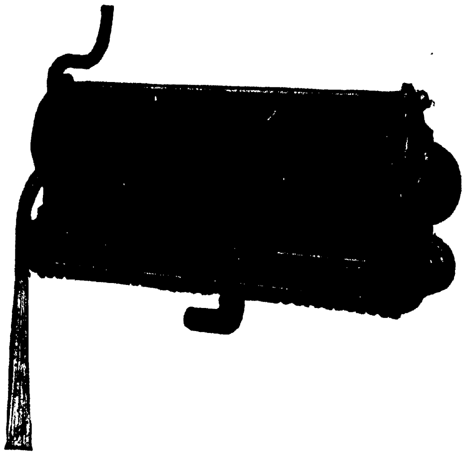

FIG. 26.—WATER-HEATER.

smaller patterns, although gas is burnt, a flue is not essential.

The large table, referred to in the general description of this room, may be about 8 ft. by 4 ft., but it will vary in size according to circumstances.

As the manufacture and repair of apparatus is sometimes undertaken in this room, such fittings as a glass-blower's table, carpenter's bench and vice may be considered to be included in a complete equipment.

A lever handle on the door is preferable to a knob, for the reason that a slight pressure with even one finger will unlatch the door; this is much appreciated when one has one's hands full. Hence, this applies more especially to the door from the preparation-room to the lecture-room, through which doorway there is much carrying of apparatus.

### ADVANCED LABORATORY.

The fittings in this room are essentially similar in detail to those described for the main laboratory; the difference will probably consist in a larger allowance of bench-space for each student.

### DARK ROOM.

As this room will probably be used principally for photographic work, a sink, draining-boards and shelves are the chief requisites. The sink can be conveniently about 24 in. by 17 in. by 3½ in. inside.

### CORRIDOR CUPBOARDS.

When the corridors are well-lighted and wide, convenient situations may be found for glazed cupboards containing specimens of crystals, ores, liquids or other chemicals of interest, or for collections of apparatus of historical or educational value. The cupboards for the specimens need not be more than 5 in. or 6 in. from front to back inside, but those for apparatus have to be somewhat larger, say about 14 in. from front to back inside. All the shelves should be adjustable in height; exclusion of dust is also essential.

# PART III.

# PHYSICAL LABORATORIES.

## I. GENERAL REQUIREMENTS AND FEATURES.

**Physics** is often satisfactorily taught in a room or group of rooms that have not been built expressly for this purpose, as the essentials are principally steady working-benches with good light and ventilation.

It is advisable that the rooms should be used solely for physical work, although there are instances when one room has to serve as both a chemical and a physical laboratory (see page 5).

In order to obtain freedom from vibration, they are most convenient on the ground floor of the building; if, however, there is a basement, it is to be preferred, when well-lighted and dry.

The **essential parts** are the laboratory and the lecture-room, either separate or combined. If under the head of physics are included frictional and voltaic electricity, magnetism, heat, light, sound and mechanics, and instruction is given in several or all of these subjects, the laboratory often either admits of subdivision or is composed of several rooms. A **few smaller rooms**, in addition to the laboratory and lecture-room, will be found very useful; these might be advantageously allotted to such purposes, as lecture-

preparation, apparatus store, balances, or dark rooms for photographic and photometric work.

An **advanced laboratory** and a **teacher's room** should be also provided, if possible.

The **lecture-room** should not be used for any other subjects that would necessitate the clearance of the lecture-table, as physical apparatus is often very delicate or very heavy, and its frequent removal is a serious consideration.

The **absence of iron** and steel is essential in the construction and fittings of rooms where the experiments carried on involve the use of magnets.

The proximity of the Engine and Dynamo Rooms must be particularly avoided, for they may be a serious source of both magnetic disturbance and of vibration.

**Vibration** may be also caused by traffic along neighbouring roads, or by heavy machinery in adjoining buildings, but it may be somewhat counteracted if taken into account when the walls and floors are being constructed.

In order that the **physical department** may form a compact whole, that can be efficiently supervised by a small number of teachers, the shape and relative position of the various rooms must be carefully considered.

**Balances** are sometimes kept in the laboratory, in addition to, or instead of, those in a separate room. If a balance-room is provided, it may be found practicable and advisable to place it so that it is equally accessible from both the chemical and the physical laboratories,

The **preparation-room** and the **apparatus-store room** will be combined or separate, according to the requirements and the space at disposal. In either case, however, it should adjoin the lecture-room and

communicate with it by means of a door or doors situated, if possible, behind the lecture-table.

Where the seats in the lecture-room are arranged on a rising gallery, it is generally practicable to construct the gallery so as to allow of the space beneath being used either as a store, or for photometric work.

In addition to the rooms already mentioned, it may be advisable to provide laboratories for instruction in such subjects as mechanics, photography, chemical physics and various branches of optical work. Experiments involving the use of considerable quantities of mercury are best conducted in rooms set apart and specially adapted for work of this nature. Then, again, a room may be devoted to collections of apparatus, models and specimens.

## DESCRIPTION OF THE ROOMS.

### THE MAIN LABORATORY.

The windows, walls, floors, etc., are referred to in detail on page 109.

The principal fittings for a laboratory for general work in physics consist of steady working-benches, cupboards, shelves and sinks. These fittings are all referred to in detail on pages 99 to 108. All students require a liberal though ever-varying allowance of space for physical work; it is, therefore, impossible to give any rule for estimating the number of students a general laboratory will accommodate. For elementary work, however, the floor-area per student, including all gangways, etc., may be taken at about 30 sq. ft.

It is now usually acknowledged that one teacher cannot satisfactorily take more than fifteen students at a time for practical work, although some authorities consider twenty is the limit.

The construction, size and disposition of the benches is a matter of considerable importance. There is still some difference of opinion among teachers as to whether it is better to have a few long fixed benches or a number of strong tables that, without much difficulty, can be moved about from time to time, as circumstances require. With the latter arrangement, it is obvious that the number of students that can be accommodated in a room of a given size is

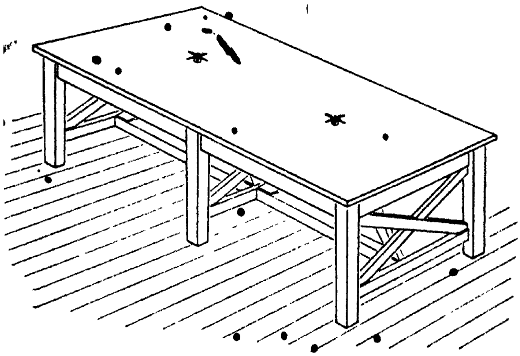

FIG. 28.—TABLE FOR PHYSICAL WORK.

smaller than with the former one. The benches and tables should be, if possible, approximately in or across the magnetic meridian for convenience of galvanometric work.

**Working-benches** will be referred to in detail later on (pages 99). Here it will be sufficient to mention that the benches are generally of two widths, the wider ones being intended to allow students to work on both sides of the bench; the narrower ones are principally fixed to the walls, or, at any rate, placed against them.

Various schemes for arranging the working-benches and the demonstrator's table were given for the chemical laboratory, and therefore need not be repeated here (see pages 12 to 14).

There should be a liberal allowance of glazed **cupboards** and **shelves**; these are best placed against the walls. Again, a considerable number of drawers are indispensable.

**Drawers** can be usually fitted to the benches and tables, without inconveniencing the student should he require to sit down to his work, and without seriously affecting the weight of a table that could be otherwise moved when necessary. **Cupboards** should be, in order to avoid these disadvantages, provided below only fixed benches, and then they should be set back some distance so as to allow space for the knees when the student is sitting down.

**Tables.**—Wood blocks laid on concrete form a suitable floor, but with an ordinary floor of boards on wood joists and also where very accurate work is to be carried on, the tables should be supported so as to be free from all vibrations of the floor. This is generally done by placing each leg of the table on a block of stone, the top of which is flush with the floor, but does not touch it; beneath the stone is a brick pier, or wall, with foundations distinct from those of the floor. If the laboratory is on an upper floor, the stone blocks can be generally supported on beams, the ends of which rest on corbels fixed below the ceiling of the room underneath. For important work the wooden benches referred to above are not sufficiently steady, and it is advisable to provide tables formed of slate slabs supported on brick piers on their own foundations. When the piers are of considerable height, alternate masses of brickwork and concrete, say, every 5 ft., have

been advocated, with the idea of impeding the transmission of vibration by change of material. One or more slabs of slate or stone built into the wall at a suitable height form steady clean shelves, where work with instruments that require careful adjustment can

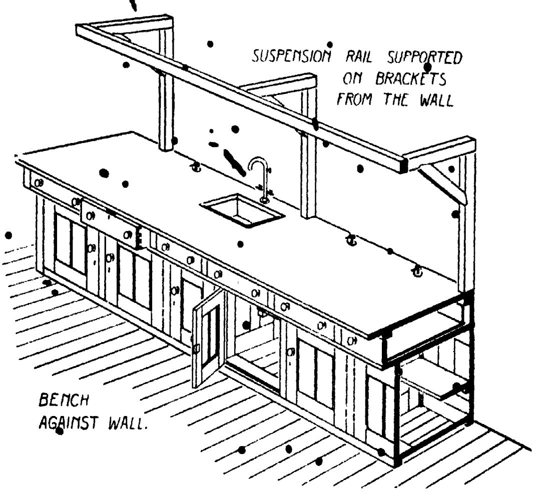


FIG. 29.—WALL-BENCH FOR A PHYSICAL LABORATORY.

be carried on with greater accuracy than on the ordinary wood-topped working-bench.

The small cathetometers now made to stand on the benches are generally sufficient for the observation of stretching of wires, reading of mercury levels in a stereometer, dipping of loaded beams, etc. Therefore a large cathetometer-stand, in the form of a brick pier with slate top 2 ft. or 3 ft. square flush with the floor, is not essential, except perhaps for very advanced work.

The **bench-tops** should be grooved near the edge to catch spilt mercury, and they should project a few inches to allow of apparatus being clamped to them.

Above some, or all, of the benches should be fixed a **rail** provided with hooks and clamps, so that apparatus may be suspended from it (see **Figure 29**).

It is a convenience to have a few small **sinks**, with water-supply, fitted on some of the benches. There should be at least one large sink, with grooved draining-board in the laboratory.

The Board of Education suggest the provision of a **mercury table**, but there are so many suitable glass or porcelain trays and basins to be now obtained that the table cannot be considered essential.

A clear **floor-space** from 15 ft. to 30 ft. in length and 5 ft. or 6 ft. wide, along which students do not require to be passing, is generally desirable for such work as the measurement of magnifying power of telescopes, curvature of mirror surfaces, etc.

A considerable expanse of **blank wall** is extremely useful in a physical laboratory, for various manipulations with pulleys and cords, springs, wires, etc.; diagrams are frequently prepared by fixing the paper against the wall-face so as to obtain, for instance, the position of the cords in the parallelogram-of-forces exercises.

A number of **boards** bolted to the wall at various levels round the room are often found extremely useful, for they afford a firm hold for screws without damaging the surface of the wall.

There may be also "mechanical arms" or **canti-levers** firmly fixed into the wall, so that pendulums, wires, etc., can be suspended from the projecting ends and experimented with. Continuous **beams** taken across from wall to wall are often provided for the same purpose.

If some **balances** are kept in the laboratory, they are best placed on shelves built in or very firmly fixed to the walls. Smaller shelves for **galvanometers** may be similarly fixed, if desired, in suitable positions.

For work with galvanometers, spectroscopes, etc., a portion of the laboratory is sometimes screened off with curtains of black velvet or similar material.

A **demonstrator's table** raised on a low platform should be provided in the laboratory for purposes of supervision, and in order that it may be used as a lecture-table.

The simplest possible provision to enable lectures to be held in a laboratory is a **black-board** fixed against the wall with a clear floor-space in front of it where the students can stand. If desired, a demonstration-table and some high desks, or some seats and desks can be placed in this space.

## BALANCE-ROOM.

If there is a separate **balance-room**, it should be readily accessible from the laboratory. The balances should be situated where there is little passing to and fro of students, otherwise it is difficult to weigh accurately, and the balances are disturbed by the air-currents caused by these movements. Nevertheless, the balance-room is sometimes used as an apparatus store or as a library and reading-room.

As already mentioned, the balances should stand on shelves firmly fixed to the wall (see details, page 110).

## APPARATUS AND STORE ROOM.

An **Apparatus and Store Room** is usually unnecessary, except in large laboratories and where the shelf and cupboard accommodation in the main laboratory and preparation-room, if there is one, is very limited.

Occasionally this room is also a **museum** for collections of apparatus and models.

All instrument and other cupboards must be not only dust-tight and dry, but also of ample size. As some of the apparatus, such as Wheatstone's bridge, monochord, air-pump, etc., are of considerable length and width, some at least of the cupboards should be rather more than a mètre long inside, and from 1 ft. 6 in. to 2 ft. deep, with adjustable shelves.

For such apparatus and accessories as calorimeters, pneumatic troughs, Bunsens, etc., unenclosed shelves may be sufficient; while for small articles, such as thermometers, lenses, magnets, etc., drawers are required.

### LECTURE-ROOM.

One or more **Lecture-rooms** will be required, unless all the lecturing is done in the laboratory.

The lectures are to a considerable extent supplemented both by experiments, and by the exhibition of apparatus, specimens, models and diagrams.

Sometimes both a physical lecture theatre and a physical lecture-room are provided, the only difference between them being in the amount of accommodation and the completeness of the lecture-table fittings. The former may be used for large gatherings of students and scientific evening lectures, and the latter for the ordinary classes, where the experiments are not so extensive or elaborate.

In either instance, the most important fitting is the **lecture-table.** The arrangement of the seats and the position of the table has been already fully gone into in connection with the chemical department.

On the back-wall of the lecture-room should be arranged one or more **black-boards,** also diagram and lantern screens.

## PREPARATION-ROOM.

A **Preparation-room** should be provided, if funds and space permit; it should communicate with the lecture-room by a door as near the lecture-table as possible. If it also adjoins the laboratory so much the better.

It is a great convenience to have a room where the apparatus and instruments required for the lectures can be selected and got ready, instead of having to do this entirely on the lecture-table itself. Besides, in this room can be kept all instruments, apparatus, models and diagrams that are in constant use for lecture purposes. These can be stored in glazed cupboards, shelves and drawers against the walls.

The other fittings required are tables and a sink; a carpenter's bench, vice, lathe, glass-blower's table, etc., are, however, extremely useful for the construction and repair of apparatus and instruments.

## ADVANCED LABORATORY.

The **Advanced Laboratory** is usually fitted very similarly to the main laboratory, but, in most instances, a somewhat smaller room suffices.

The principal fittings are steady working-benches, cupboards, shelves, drawers and a sink.

## TEACHER'S ROOM.

The **Teacher** requires a room or, better still, two adjoining rooms, for use as a study and a private laboratory; the former where he can read, write, and interview students, and the latter where he can, without fear of disturbance, carry on any experimental work he may be engaged upon.

The study requires the usual writing-table, book-cases and cupboards, and the laboratory a steady

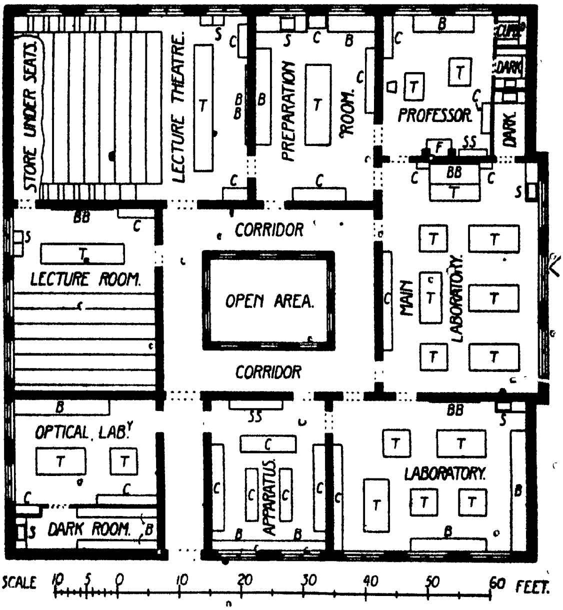


FIG. 30.

B. = Bench.
BB. = Black-board.
C. = Cupboard.
F. = Fireplace.

S. = Sink.
SS. = Shelves
T. = Table

working-bench, cupboards, shelves, drawers and a sink.

## DARK ROOM.

A Dark room for photometric, photographic or spectroscopic work is convenient, although part of the

laboratory may be screened off for this work. If it is a separate room, particular care should be taken to ensure good ventilation, without the admission of daylight.

As reliable dark blinds can now be obtained, the absence of windows is not essential; the walls are frequently blackened.

If there is a laboratory devoted to optical work, all the windows in it should have dark blinds, so that the light may be reduced, when desired.

**Figure 30** is a plan of a Physical Department suitable for a college or technical school. It illustrates the suggestions that have been made as to the relative position of the different rooms and the arrangement of the necessary fittings.

## DETAILED DESCRIPTION OF THE FITTINGS.

### THE MAIN LABORATORY.

**Working-benches and Tables.**—The *height* of the table-top depends, to some extent, on the age of the students who are to work at it. As a general rule, 2 ft. 9 in. or 2 ft. 10 in. is found to be a suitable height for students up to about sixteen years old, and 3 ft. for all others.

The *width* across the table-top is determined not only by the distance a student can easily reach without bending, but also by the size of the apparatus he may have to work with, as some of it requires considerable space. Four feet is the usual width for a double bench or table; although, for elementary work, it may be possible to do with 3 ft. 6 in., or even 3 ft., if necessary. If students work only along one side of the table, it need not be more than 2 ft. 6 in. wide.

The work in a physical laboratory is of such an extremely variable kind that the amount of table-space required is an ever-varying quantity. In elementary laboratories, a *length* of table-top of from 2 ft. 8 in. to 4 ft. is usually allotted to each worker, or to each pair of students, if they work in couples. To work in pairs is a common practice, which has the advantage of

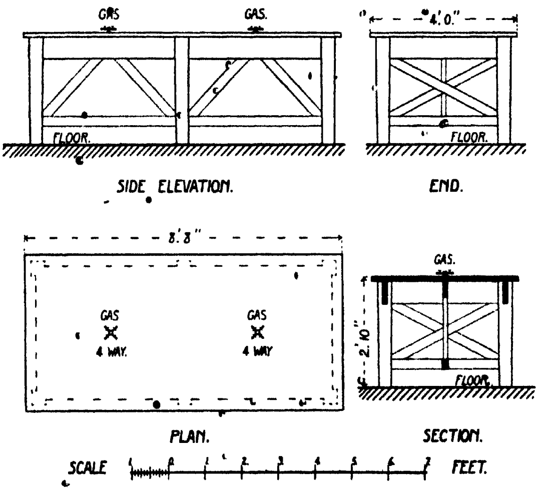


FIG. 31.—TABLE FOR PHYSICAL WORK.

lessening the stock of apparatus required; besides, many of the experiments cannot well be carried out single-handed.

*Gangways*, between the tables, vary in width, from 2 ft. 6 in. to 6 ft., according to whether there will be a single or a double row of students encroaching on it, or none at all, and also somewhat according to the total floor-area to be dealt with. It has been already

mentioned (page 91) that short tables, although very convenient in many respects, are less economical of floor-space than long ones; the former are also relatively more expensive than the latter.

In a narrow laboratory lighted along one side only, if the ends of the *tables* have to be placed against the wall, it is generally best to put them between the windows, unless the latter are very far apart.

For steadiness, and also on account of the weight of the teak top, the *tables* should be strongly framed, and the legs should be massive, say $3\frac{1}{2}$ in. square, tapering to 3 in. at the bottom, and not more than about 4 ft. apart. In order to counteract any irregularities in the floor, a four-legged table sometimes has one leg purposely made an inch or two shorter than the other three, so that wedges and blocks can be inserted under that leg.

The arguments for and against cupboards and drawers in the benches and tables have already been capitulated (page 91). Sometimes there are either drawers, or cupboards, in the benches, and sometimes both; in the last case, the drawers are in a row under the bench-top, with the cupboards below them. It is rarely the custom to provide each student with a separate set of apparatus, as is often done in a chemical laboratory. Hence, if there are *drawers* fitted to the tables, each contains a number of such small articles as rubber and glass tubing, electric wires, etc., which are included in the general stock of apparatus. A convenient size for these drawers is 5 in. deep, inside, about 18 in. wide from front to back, and 22 in. long. A wood turn-button screwed either to the back of the drawer, or to the frame, is convenient in preventing the drawer from being unintentionally pulled out too far, and yet allows it to be removed for cleaning, etc.

If there are *cupboards* fitted to the benches, they are usually set 3 in. or 4 in. back from the drawer fronts,

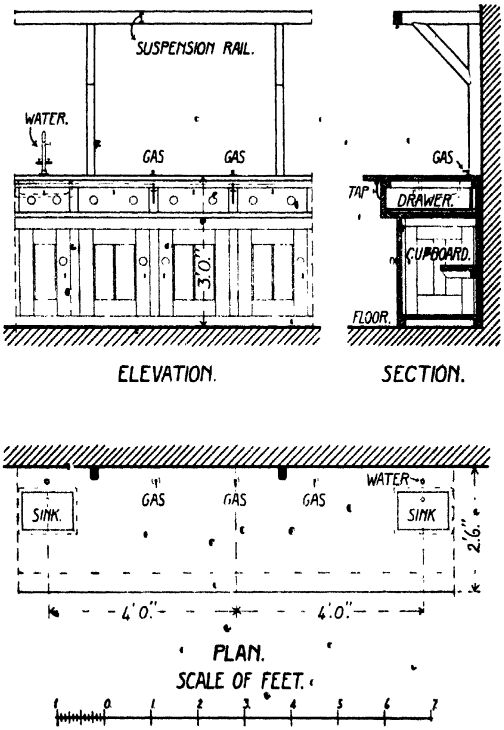


FIG. 32.—PORTION OF WALL-BENCH FOR PHYSICAL LABORATORY.

as already mentioned (page 92). These cupboards should be as large as possible, and should have shelves inside, suitably arranged as to width and height for

the particular apparatus that will be stored in each cupboard.

Sometimes long cupboards are constructed down the middle of the double benches, and used for the reception of long pieces of apparatus.

A *toe-space*, or recess, about 3 in. high, should be formed at the floor-level below the front portion of the cupboards; this avoids the unsightly appearance due to the students' feet coming in contact with the wood-work, and allows the students to stand or sit close up to the bench when at work. The depth of this recess, of course, varies with the projections of the bench-top and drawers. The bench-top should overhang 4 in. or 5 in., and should have, on the upper surface near the edge, a continuous half-round groove, 1 in. wide, to catch spilt mercury.

The *suspension-rails*, referred to above (page 94), can be made of either brass tubes about 1 in. in diameter, or wood, say, 3 in. deep and 2 in. wide, firmly fixed 3 ft. or 3 ft. 6 in. above the bench-top, on standards not more than 4 ft. 6 in. apart. In the case of wall-benches, brackets should be used instead of standards. If they are not perfectly firm, they are worse than useless. The rails should carry a number of hooks and clamps.

*Materials.*—The top of the bench, or table, is almost invariably made of teak, a wood which withstands heat and resists the action of acids and alkalies very well. It is usual, however, to treat it, from time to time, with dissolved or melted paraffin, or with oil, the object being to render it non-absorbent, and free from tendency to crack. Sometimes other woods are used, such as mahogany, oak, pitch-pine, or even deal, but it is essential, for some experiments, that the bench-top should be a perfectly flat surface, and oak, for instance, often has an objectionable tendency to warp and twist.

The remainder of the bench or table is most frequently made in pitch-pine, but stained American whitewood is coming somewhat into favour, as its appearance is good, and it is cheaper and more easily worked than pitch-pine. Amongst the other woods used for this purpose are orham, red deal, oak and American walnut.

In order to avoid crevices and angles, in which dust, etc., may accumulate, it is advisable to have as few mouldings as possible, and only "flush" panels.

When *bench-sinks* are provided, it is usually only on some of the wall-benches. They can be quite small, say 13 in. by 9 in. by 5 in. deep, inside, and placed so that each one is accessible from two adjacent working-places. The sinks are generally made of stoneware, or fireclay, with the inside glazed and of a white or cream colour, but sheet-lead or enamelled iron are sometimes employed. Sinks are best fixed under the bench-top, the edges of which should be throated, then spilt liquids can be safely washed direct into them, but they are difficult to get out and replace, if fractured. As it is only for a comparatively small number of experiments that the sinks would be used, it is very convenient to have for all other work an interrupted bench-top; hence, wooden covers are sometimes provided for these sinks. The covers may be loose, sliding or hinged. It is difficult to know what to do with loose covers when they are removed, unless special cupboards or drawers are provided, in which each one can be placed. Sliding covers necessitate the sliding-forward of a considerable portion of the bench-top, part of which has to be hinged to fall over the front of the bench when the sink is used, and the hinges, unless unusually strong, soon get broken. This same disadvantage applies even more forcibly to hinged covers. A hole should be drilled through the cover immediately below the nozzle of the

water-tap, so that any water dripping from the tap can pass into the sink when the cover is in its place. Two additional small *branch-cocks* for connecting to condensers or filter-pumps are advisable, but a low-pressure supply is best for use in a condenser, and high-pressure for filtering purposes. It is most important that the *waste-pipes* from the sinks are easily accessible throughout their entire length, in order that any leakage or stoppage that may occur may be immediately noticed and readily located and rectified.

*Gas* is usually laid on to the fixed benches and tables for the use of the students, for heating purposes, with four-way taps, and nozzles suitable for attaching rubber-tubing, in the centre of short double benches, or down the middle of long ones at intervals of from 3 ft. 6 in. to 4 ft. 6 in. When the tables are movable, the gas is brought by means of flexible tubing from the nearest point. Sometimes there is also a gas-jet giving a luminous flame for glass-bending.

**A Cabinet or Nest of Drawers**, several of which are only 2 in. or 3 in. deep, are most useful for storing thermometers, drawing instruments, slide-rules, short measuring rods, lenses, prisms, etc.

One or two **Large Sinks** are required in the laboratory for use when some quantity of water is being dealt with, and also for the cleansing of apparatus. A convenient size is 28 in. by 18 in., by 8 in. deep, inside; a glazed stoneware sink can be kept cleaner than one of wood lead-lined, but with the latter the fracture of glass vessels is less frequent. There should be, in all cases, a grooved draining-board, preferably of teak or cherry wood, and about 2 ft. in length. It is convenient to have both hot and cold

water laid on. The height of the taps above the sink requires careful adjustment to the circumstances, as it may be found some of the apparatus is of considerable length and size. A height of 24 in. above the bottom of the sink will be probably found advisable. The top of the sink should be about 2 ft. 9 in. above the floor.

The **Demonstrator's Table** should be about 8 ft. long and 2 ft. 6 in. wide, and 3 ft. high, with the platform extending at least 3 ft. 6 in. behind it. It is usual to make the platform from 6 in. to 12 in. high, and it is better not to exceed this limit, as a rise of more than two steps is inconvenient. The height of the platform should be regulated, to some extent, by the distance of the furthest benches.

At the back, beneath the table-top, which is usually of teak, and grooved at the edge to catch spilt mercury, is a series of drawers, with cupboards and recesses below; the recesses are similar to the cupboards, with the omission of the doors. A continuous toe-space should be formed at the floor-level. There should be two or three gas-connections on the table. A pneumatic trough is not often required, but, if constructed, it can be conveniently about 27 in. by 19 in., by 16 in. deep, inside, with glass front and back, and some means behind for illuminating it artificially. For emptying the trough a waste-pipe connected to the drains is necessary, and, if possible, water should be laid on. It is convenient to have a hinged or sliding wooden lid, flush with the table-top, to cover over the trough when it is not in use.

A **Black-board** must be arranged for somewhere in the laboratory, preferably against the wall and near the demonstrator's table. The materials and arrangements

that can be employed were fully discussed in connection with the chemical laboratory (page 66). The sizes then suggested hold good here.

**Desks.**—In front of the black-board there may be placed some desks, at which the students can either stand or sit and take notes. The desks for standing-at may be merely iron standards, to fix into the floor, carrying book-boards that can be clamped at any desired height between about 3 ft. 2 in. and 3 ft. 10 in. The desks for sitting-at may be a simple pattern of long desk and bench.

A **Mercury Table** differs from an ordinary one in the nature of the top, which is generally of hardwood, well-seasoned, with a series of shallow channels to lead the mercury to a plugged outlet; there is also a fillet projecting up about ¾ in., fixed along each edge.

**The Boards bolted to the Walls**, as suggested above (page 94), can be at various levels, from 3 ft. to 7 ft. above the floor, while the beams and cantilevers should be at least 7 ft. or 8 ft. high, the latter projecting 3 ft. or 4 ft. out from the wall.

**Cupboards** for the reception of apparatus are best placed against the wall. The doors should be glazed, so that the contents are visible, and hinged in the usual manner, as sliding doors do not as a rule work so well, and are not so convenient. The cupboards should be from 1 ft. 6 in. to 2 ft. wide from back to front inside; some of them, at any rate, should be of considerable length, say rather more than a metre long inside. The shelves should be adjustable in height. If circumstances permit, the top of the cupboards from the floor ought not to exceed 6 ft. 6 in. or 7 ft., in order that

the highest shelf is within easy reach. Freedom from moisture and dust is essential. A toe-space at the floor-level, similar to that suggested for the benches (page 103), is advisable.

A tall cupboard, extending from the floor up to a height of 10 ft. or 12 ft., is useful for storing unusually long pieces of apparatus, such as potentiometer, long inclined plane, wooden optical bench, etc.

**Shelves** on the walls should be also provided in the laboratory; their width and distance apart vertically will depend on the use to which they will be put.

Shelves for *balances* are best supported entirely by the walls; suggestions as to suitable material, size, etc., for these shelves are given below ("Balance-room," page 110).

Special shelves for *mirror galvanometers* are convenient, in order to obtain as much freedom from vibration as possible. It is a good plan to have slabs of slate or hardwood, about 12 in. square, built into the wall, about 4 ft. 4 in. above the floor, in convenient positions in the laboratory. Scales, at about a metre from the galvanometers, may be fixed to the wall and hinged to fold back against it. If there is a small adjustable mirror at the back, one of the gas or other lights illuminating the laboratory can be utilised, instead of providing a support for a special oil or other lamp.

There are endless devices and appliances that can be adopted with a view to increasing the convenience of the laboratory, and improving the quality of the work that can be carried on in it. For example, electric current terminals can be provided on the benches, or steam can be laid on for heat experiments, etc., but these refinements and elaborations

depend entirely on the requirements in each individual instance.

**Stools.**—It is usual to provide stools for the students to sit upon. These should be strongly framed together, and have a wood seat about 12 in. by 10 in., and 24 in. or 26 in. high. In girls' schools, where the furniture is not treated so roughly as in boys' schools, some slight extra comfort can be given by having low backs to the stools.

**Windows, etc.**—As it is only for a comparatively few experiments that considerable height is required, a lofty room can be hardly said to be necessary. No definite height of so many feet can be given, as it should bear some relation to the class of work to be done, and also to the size of the room. The minimum height for rooms used for teaching purposes is given for various areas in the Board of Education Rules, and also by the authorities on school-planning.

A top-light is not essential. Wall-space, however, as already mentioned, is most useful, not only for cupboards, but also for exercises in mechanics, etc. Hence it may be sometimes advisable to have a sky-light, where one is possible, in order to reduce the number of windows otherwise necessary to properly light the room. However, as the physical laboratory is generally on the ground-floor or basement, a top-light is, in many cases, impossible.

A south aspect is not advisable, as the laboratory would then become inconveniently hot in summer. One advantage, however, of windows in a south wall is that an outside mirror or heliostat can be used for spectroscopic work.

No coloured glass should be used in any of the

windows; they should be all made to open. Where there is no bench or other fitting in front of the window, it is sometimes convenient to be able to put apparatus outside; an unusually wide stone sill is then advisable, if circumstances permit. The window-board should be at such a height that it can be conveniently used as a shelf. The space between the window-board and the floor is usually wasted; this can be avoided by keeping the wall thin there, and fitting up a cupboard or a series of shelves or pigeon-holes in the recess thus obtained.

**Walls and Floors.**—The question of suitable materials for walls and floors was gone into fully on page 70 ("Chemical Laboratories"), and therefore need not be repeated here. The suggestions then made regarding the relieving of blank wall-spaces with colour, simple decoration and suitable pictures, apply, of course, to physical as well as chemical laboratories.

## BALANCE-ROOM.

The balance-shelves may be of wood, slate, or concrete, carried on stone, wood or iron brackets, firmly fixed into or against the wall. In order to prevent one student shaking the slab on which neighbouring balances rest, each balance may stand on a separate shelf of a length varying from 1 ft. 6 in. to 3 ft., according to the size of the balance. A convenient width for the shelf is found to be 1 ft. 7 in. It is the more usual practice for the students to sit when weighing, but if it is preferred they should stand, the shelf must be about 3 ft. 9 in. above the floor, instead of about 3 ft. The shelves must afford a clean, level and perfectly steady surface. Mahogany is one of the best woods to employ. It is a good practice to have a piece of

plate-glass, about 8 in. wide, laid on a strip of green baize along the front of the shelf. It affords a clean surface on which the article to be weighed may be placed, and there is also the possibility of one of the weights being accidentally dropped. Behind the balance the surface of the wall should be white, so as to be both clean and reflecting.

When it is required to illuminate the balance artificially, and electricity is available, a portable standard connected to a wall-plug is very convenient. The lamp should be on an arm so as not to interfere with the manipulations; a reflector can be used to throw the light on the scale and keep it out of the students' eyes.

If this room is also an Apparatus Store, cupboards and shelves similar to those already described (page 107) will be needed; if as a Library and Reading-room, such furniture as a table, chairs, and bookcases. As the current numbers of physical periodicals are often set out on it, the table can be, with advantage, considerably wider than one required merely for reading and writing purposes, a width from 4 ft. 6 in. to 6 ft. often being advisable. Occasionally a special table is also provided, on which diagrams can be prepared. This table-top must be of considerable area, about 6 ft. by 4 ft., or 10 ft. by 6 ft., and it is convenient if it is adjustable to any angle; the space beneath can be sometimes utilised as a diagram-chest.

### Apparatus and Store Room.

The cupboards and other fittings in this room are essentially similar to those in the main laboratory, but will be probably more extensive both in height and length.

## Lecture-room.

The fittings in the physical lecture-room are almost identical with those already described in detail for the chemical department (pages 78 to 85). Such fittings, however, as draught-closets and reagent-shelves would be seldom, if ever, used; hence, the space they would occupy is better allotted to glazed cupboards or shelves for apparatus required for the lectures.

It is convenient to have a dead-beat galvanometer permanently mounted on a wall-bracket; if, however, there is much vibration, the galvanometer should be hung from the ceiling on a shelf slung by three cords from a mass of metal (not iron) which is suspended by a long chain or cord. If a semi-transparent scale, at about a metre from the galvanometer, is used, no special darkening of the room is necessary. If there is a window with a south aspect close to one end of the lecture-table, a beam of sunlight can be reflected on to the table and utilised, if desired, when the sun is shining.

Some means of suspension over the lecture-table is convenient; if a rail similar to those on the laboratory benches is used, it must not be low or it will obstruct the students' view of the table-top or black-board. Openings in the ceiling over the lecture-table are often useful.

## Preparation-room.

The cupboards, shelves, drawers, sink and working-benches in this room can be similar to those described for the main laboratory; the size of the working bench or benches varies according to the requirements and the space that is available.

A water-heater, as suggested for the chemical laboratory preparation-room (page 86), may be found useful if hot water cannot be laid on to the sink.

If the accommodation allows, a large table in the centre of the room is very useful on which to set out apparatus; it can be about 8 ft. by 4 ft. by 2 ft. 6 in. high, but it will vary in size according to circumstances.

Diagrams are sometimes prepared on this table,

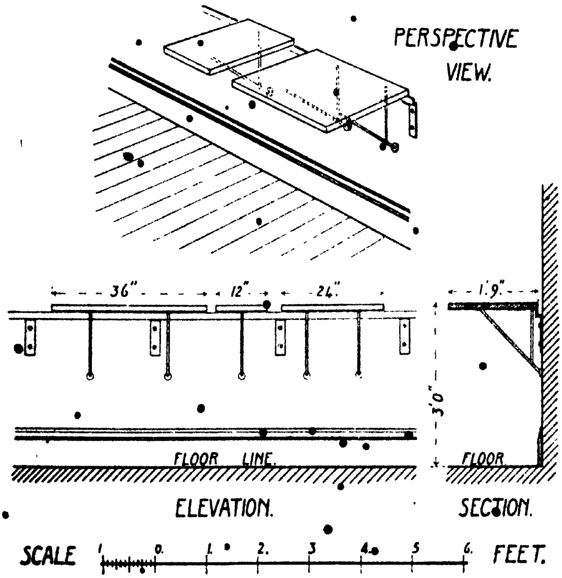


FIG. 33.—MOVABLE WALL-SHELVES.

but, for this work, it is more convenient to have a table-top which can be set at any desired angle.

The advantages of having a lever handle instead of a knob on the preparation-room door were mentioned on page 87.

C.L.

## ADVANCED LABORATORY.

In the advanced laboratory the work may from its very varied and more elaborate character demand even greater adaptability of the fittings to circumstances than is the case in the main laboratory, where the work is more elementary. Hence, several short tables that may be used singly, or conjointly, in any part of the laboratory are often preferred to longer tables.

Similarly, instead of long wall-benches, it is a good plan to have a number of movable shelves of varying lengths arranged to hook on to a continuous angle-iron fixed along one wall at about 3 ft. above the floor (see Figure 33). A working-space of any desired length can be thus readily obtained anywhere along the wall. These shelves should be about 1 ft. 9 in. wide, in, say, three different lengths of 12 in., 24 in., and 36 in., and made preferably of teak. Each shelf should have two square hooks about 1½ in. wide and 1¼ in. long, and be kept horizontal by one or two iron brackets fixed to the underside; a small pad of felt, at the end of the bracket where it rests against the wall, assists the steadiness and prevents the wall-surface being damaged.

## TEACHER'S ROOM.

The fittings in this room are essentially similar in detail to those already described.

## DARK ROOM.

When the dark room is used for photometric work, such as a comparison of electric or other lights, one or more benches, from 10 ft. to 15 ft. long and about 1 ft. 6 in. wide and 3 ft. high, are required. Occasionally these benches are as much as 25 ft. long.

For photographic work, the principal fitting that

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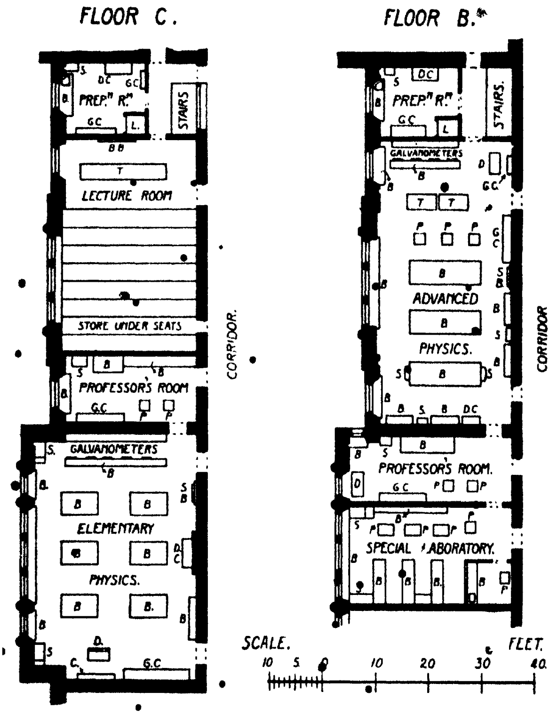


| | |
|---|---|
| B. = Bench. | D. = Desk. |
| BB. = Black-board | L. = Lift. |
| SB. = Switch-board. | P. = Pier. |
| C. = Cupboard. | S. = Sink |
| DC. = Draught-closet. | T. = Table. |
| GC. = Glazed Cupboard. | |

FIG. 34.

**Plans of Physical Laboratories, showing the fittings. A. W. S. Cross, F.R.I.B.A., architect.**

should be provided is a sink, preferably of glazed ware, about 24 in. by 17 in. by 3½ in. deep inside, with water supply and waste-pipes, draining-boards and shelves. If there is a window, a dark blind must be drawn across it to shut out the daylight; care should be taken to see that the edges of the blind slide in grooves at least 3 in. deep. Almost any dark material can be used, but as the probability of the blind getting out of the grooves, owing to draughts or other causes, depends chiefly on its stiffness, a thin material painted both sides is best. A spring-roller is generally employed, and it is fixed either along the top or bottom of the window; there are, however, conditions when the blinds are best drawn horizontally across windows or skylights.

In order to prevent access of light, it may be advisable to fit, along the bottom of the door, a "draught-excluder," that is, a strip of wood or rubber which automatically falls and forms a tight joint with the floor when the door is closed.

The necessity for ensuring good ventilation in the room has been already mentioned (page 99).

# PART IV.

# VENTILATION, WARMING AND LIGHTING.

## VENTILATION.

### GENERAL PRINCIPLES.

**Ventilation** is the removal of the foul air in a building and its replacement by fresh air.

In **True Ventilation** the object to be attained should be to continuously supply air of proper quantity, quality, temperature, humidity, and distribution, without apparent draught or variation of temperature, and to completely remove the vitiated air without allowing it to mix with the fresh-air currents. That ventilation is necessary in all buildings is obvious, especially when it is realised that the percentage of oxygen in expired air is only $\frac{4}{5}$ths of the percentage in fresh air, while the percentage of carbonic acid is over one hundred times greater in expired air than in fresh air.

It is a matter of very great importance in a **chemical laboratory**, as the atmosphere is rendered impure, not only by the respiration of the occupants and the products of combustion from gas-burners or other means of artificial lighting, but also by the various gases and fumes evolved in the course of the work. The object of the draught closets and hoods previously described is to immediately carry off these gases and fumes before they have had time to diffuse through the air of the laboratory.

Everyone must be familiar with the unpleasant effects due to a badly-ventilated room, such as headache, feeling of lassitude and general weakness, but the exact cause of these rapidly-developed sensations is still somewhat uncertain. At any rate, a continuous or frequent exposure to such an atmosphere undoubtedly leads to ill-health and increases the liability to many diseases, all of which can be directly attributed to impure air.

The **amount of carbonic acid** present is usually taken as the means for expressing the purity or impurity of the air: it can be estimated by Dr. Haldane's portable apparatus. The normal percentage of carbonic acid in the open air is in towns about 0·035 and in the country 0·030, while the limit that has hitherto been suggested is 0·06 per cent. The Departmental Committee appointed to enquire into the Ventilation of Workshops state, however, in their report, issued in November, 1902, that they consider workshops could be reasonably expected to be kept within a carbon-dioxide limit of 0·10 per cent., unless gas is burning.

A man produces in an hour about 1 c. ft. of carbon dioxide, which, if allowed to diffuse freely through 4,000 c. ft. of fresh air, would raise its percentage of carbonic acid from 0·035 to the above-mentioned limit of 0·06; if the 0·10 standard of purity is considered sufficient, the bulk of air diffused through will be only about 1,540 c. ft. instead of 4,000. These theoretical amounts of air to be extracted per hour per head are several hundreds of times greater than the volume of the noxious gases and vapours actually expired by a man in an hour. As no means, however, exist of drawing off or absorbing the impurities as they are being given out, and before they have had time to foul the pure air, resort must be had to abundant dilution and continuous renewal.

One ordinary gas-jet or three incandescent gas-burners contaminate the atmosphere about as much as four men.

There are two rough and ready ways of arriving at the approximate minimum **seating capacity** of a class-room.

(1) Divide the total floor-area in square feet by ten.*

(2) Divide the total cubical area in cubic feet by 120,† neglecting all air-space more than 12 ft. above the floor. The latter method is misleading, as ample air-space per head does not necessarily ensure sufficient ventilation, and large rooms require a proportionately larger number of gas-lights than small ones.

It has already been mentioned that, in a general chemical laboratory, the allowance of floor-space per student is from 30 to 36 sq. ft., including all gangways.

Authorities differ very widely as to the quantity of air that ought to be supplied in schools, the amount advocated varying from 600 to 2,400 c. ft. per student per hour. As it is generally impossible to extract the whole of the expired and foul air, without causing serious draughts, one must be content to partially extract and largely dilute it.

**Draughts** are complained of if the incoming air is too cold, too dry, or too moist, or if the velocity of the current is too great; the speed at the inlet should not exceed 3 to 5 ft. per second,‡ particularly if the temperature of the air is below 60° Fahr. As the average

* For new Higher Grade Schools this figure must be increased to thirteen if dual desks are used, and to sixteen if the desks are arranged singly.

† For new Public Elementary Schools this figure must be increased to 130 if the total floor-area is between 360 and 600 sq. ft., and to 140 if the total floor-area exceeds 600 sq. ft.

‡ Recent tests by Messrs. Ashwell and Nesbit, at the Leicester Technical School, showed that there was no discomfort when the velocity of the incoming air was 6 and even 9 ft. per second.

amount of water vapour suspended in the atmosphere in England is about 65 per cent. of the amount that saturated air under the same conditions would hold, the temperature of the incoming air should not differ by more than 10 degrees Fahr. from that of the air in the room.

In reality, the comfort of a room depends, to a great extent, on the amount of moisture in the air and not solely on the temperature indicated by an ordinary thermometer.

As it is the mean temperature of the air, more than that of the walls, that is required to be known, a thermometer should be suspended near the middle of the room and not hung against the wall.

**Fresh air** requires to be warmed in winter before it is admitted into the room, and if practicable it may be, with advantage, cooled slightly in summer.

In every room to be ventilated one or more **air inlets** and **outlets** must be provided. In order to diffuse the air, each opening should have a grating, detachable if possible for cleaning purposes, and the total area of the openings in each grating should slightly exceed the sectional area of the duct, but should not be greater than 60 sq. in. Where there are several inlets and outlets in a room, either draughts, or inadequate ventilation, will be experienced in some parts of it, unless the motive power and the size of the ducts are so arranged as to cause air-currents of equal volume and velocity through the various inlets and outlets respectively. In order to diminish the chance of any air entering, instead of leaving by means of the outlets, it is advisable, especially if the motive power is not strong, that the total area of the inlets slightly exceeds that of the outlets. The Board of Education require a minimum of 2½ sq. in. per pupil for the inlets and 2 sq. in. for the outlets.

In schools the air of the room should be reckoned to be changed about three times an hour.

The **general ventilation** of a building may be effected in various ways, but it always has to be considered in conjunction with the scheme for regulating the temperature of the air in the building.

**Ventilation** may be natural or artificial.

**Natural ventilation** is chiefly due to the wind and to differences in the temperature, moisture, and purity of the air, while in **artificial ventilation** the movement of the air is brought about either by heat or by such mechanical means as fans, pumps and water-jets.

## NATURAL METHODS.

In **natural ventilation**, the motive power is uncertain and irregular in action. The action of the wind in exposed sites is often overlooked; by exerting a pressure on one side of the building and an aspirating action on the other side, it may seriously upset both the ventilating and heating arrangements, at any rate, for a time.* The wind in England averages 14 miles an hour, and a so-called "still" atmosphere is, in reality, air moving from 1 to 1½ miles an hour.

In this system the fresh air cannot be well distributed, and not being warmed by artificial means, down-draughts are frequently experienced. It can be, however, cleansed by being passed through a screen of muslin or cotton wool, but these filters retard the current and require frequent renewal; with the same object, the air is sometimes directed on to the surface of some water or glycerine.

**The inlet ducts** should be short and admit of being

* This has been experienced at Girton College, Cambridge.

cleaned out from time to time, and should have the opening into the room about 6 ft. above the floor. This opening should be capable of being partially closed, as the force and direction of the wind is always changing, and it should be arranged to diffuse the fresh air in an upward direction. The diffusion is often assisted by slightly enlarging the mouth of the duct towards the opening into the room and an upward impulse can be given to the air by the use of a Sherringham ventilator or short vertical Tobin tube instead of a plain grating. Fresh air can be also admitted at the windows, either above the head of the frame, or between the meeting-rails of double-hung sashes by providing a deep bead on the inside of the sill.

The foul air should escape through one or more **extract flues** or pipes, which are as straight and smooth inside as possible. If there is more than one flue communicating with the same room, they must be of equal height, to avoid differences of air-pressure. The outlets from the room are either in the ceiling or walls, while the openings into the outer air are generally at the level of the ridge or the chimneys, and are provided with louvres, flap-valves, extractors, or revolving cowls: all these latter devices are intended to prevent down-draughts and to increase the extraction of the foul air. Frequently a mica-flap or an Arnott's tin-plate valve is fixed near the ceiling communicating with the smoke-flue from the fireplace, or better still, with a special foul-air flue. In the former case, the ventilator must not be actually in the side of the smoke flue, but in a horizontal connecting flue, which need be only some 12 in. long, just sufficient for the air in it to act as a buffer. The chance is thus lessened of smoke or down-draught escaping into the room through the valves, and the closing of the valves, a noisy

process when of mica,* is somewhat less forcible. The flue-opening immediately above the fire should not be larger than absolutely necessary to efficiently lead away the smoke, and its sectional area, plus that of the ventilator, should be, if possible, approximately equal to the cross-section of the chimney-flue. The special foul-air vent, however, must be carried up, to increase its aspirating tendency, against a smoke-flue, or better still, between two such flues, and have louvres or gratings on both sides of the stack about 2 ft. below the top, so as to avoid any smoke getting blown down. The flap-valve can be, in this case, of oiled silk, if preferred. These ventilating flues should not be complicated with many valves and louvres, otherwise they will not act efficiently in still weather when most required. When there are outlets near the ceiling, it is sometimes considered that the warm fresh-air introduced in winter will escape without warming and purifying the general atmosphere of the room, and so some openings are provided near the floor-level for winter use only, both sets of outlets being fitted with closing valves.

As an open fire extracts air near the floor-level, air-currents with a downward tendency are caused, and for this reason any additional outlets are sometimes placed near the floor. The chief argument adduced against **downward ventilation** is that, although carbonic acid is more than half as heavy again as air, expired air, when it issues from the lungs, is usually about equal in weight to air at 90° Fahr.; it, therefore, rises until its temperature has fallen to that of the surrounding air. By that time it has diffused in all directions, and the mixture thus formed has the same

* The Arnott valve, mentioned above, can be, however, made nearly noiseless by strips of leather or cork on the edges.

*specific gravity as fresh air, owing to the increase of* carbonic acid and water vapour and decrease of oxygen. If, however, the ventilation is very powerful, there is the risk that expired air may be breathed over again by persons in the room before it has been much diluted.

The mixture of hot air and fumes from gas-burners, however, always goes straight up to, and accumulates at, the ceiling-level, unless allowed to escape through proper outlets formed there for this purpose. The Board of Education suggest, for ventilating purposes, the provision in class-rooms of a small fanlight hung on centres near the ceiling and as far as possible from the windows, by which the room is lighted.

## ARTIFICIAL VENTILATION.

In **Artificial ventilation** the air-currents may be caused by (1) heat, or (2) mechanical means.

### (1.) Air-currents caused by heat.

The heat is used either to extract the foul air or to warm the fresh air, or for both purposes. The source of heat may be a stove or furnace, hot-water or steam pipes or gas-jets. This system is somewhat irregular in action without constant attention in adjusting the temperature of the source of heat, so as to allow for the ever-varying temperature and movement of the external air. Both open and closed stoves can be generally arranged to draw in and warm a constant current of outside air, which is then delivered into the room at a suitable height. By means of these so-called "warm-air grates," twice as much air is dealt with and space warmed, as compared with the ordinary ones. With the exception of the somewhat higher first

cost, warm-air grates have only one disadvantage, and that is the difficulty of cleaning out the air-chambers; this is, however, a serious one, more especially in towns. Careful experiments have proved that the amount of fuel consumed is not any greater with a warm-air grate than with a similar one without an air-heating arrangement; the difference is merely that a larger proportion of the heat due to the combustion of the fuel is utilised in the room.

An ordinary chimney-flue cannot be safely relied upon to carry off, on an average, more than from 5,000 to 15,000 c. ft. per hour. Although the size of the flue is not always stated, it is safe to say that the amounts usually given in books are very much too high, owing probably to reliance on a formula, instead of using an anemometer.

If a hot-water or steam radiator is placed against an outside wall of a room, a constant stream of fresh air can be readily drawn in and warmed, but, when the heating apparatus is not in use, this arrangement is merely an opening, through which it is possible for fresh air to pass (page 140).

To put a gas-burner at the base of a vertical flue is a simple method of increasing the extracting power of the flue and one very largely adopted in chemical laboratories, especially for creating a draught in the fume-closets. To obtain the best results, the light should be a little above the bottom of the flue, but usually it is found most convenient to place it at the lowest point. If the burner is placed in the flue at a point below the outlet from the draught-closet, it is then out of the current of strong fumes, and is therefore less liable to be seriously corroded. Otherwise it is better to make the burner and pipes of less easily acted-upon material than the usual iron and brass (see page 51).

Mr. Thos. Fletcher, F.C.S., of Warrington, has made a number of experiments* on the use of gas for ventilation. He used a single vertical tube 6 in. in diameter and 12 ft. high, in which there were no natural currents either up or down. Both flat-flame and gauze "atmospheric" burners were tried under varying pressures. In one hour, 2,460 c. ft. of air were exhausted by consuming 1 c. ft. of coal-gas. To double this velocity, the gas-consumption had to be increased to 8 c. ft. per hour, reducing the efficiency of the gas to ¼. With an air temperature of 62° Fahr., the temperature at the top of the tube was 82° Fahr. in the first experiment, and 137° Fahr. in the latter one. When the flue was shortened to 6 ft., the duty was reduced 20 per cent., and it would have probably been much reduced if the flue had been larger and longer.

The conclusions to which he came were: that the quantity of gas required for any ventilating flue should not exceed 4 c. ft. per hour for each circular foot of sectional area, and that the efficiency of "atmospheric" and luminous flames is precisely the same.

"Atmospheric" burners are troublesome in practice and should not be used; while Bray's union jets are easily and cheaply renewed and, being luminous, are more likely to receive proper attention.

Sometimes a metal plate or open metal tube or cone has been suspended above the burner, on the assumption that the heated surface would assist in raising the temperature (and therefore the velocity) of the air in the flue. It has been proved, however, that, in reality, these pipes and cones retard the velocity of the air from 5 to 15 per cent., according to the shape used, owing

* "Coal Gas as a Fuel," 5th edition.

principally to the friction caused by the increase of surface.*

There are various formulæ used for calculating the velocity of the current in a hot-air flue, but they are mostly on the following basis. The velocity of falling bodies is approximately eight times the square root of the height fallen through. The height is, theoretically, that from the point where the air enters to the point where it escapes, multiplied by the difference between the internal and external temperatures, and again by the expansion of air per degree Fahr. ($\frac{1}{500}$).

The friction varies directly with the square of the velocity, and with the amount of internal surface in the flue, but indirectly with its sectional area. A deduction of $\frac{1}{4}$ is usually made for friction; if, however, the flues are long and narrow an allowance of $\frac{1}{2}$ may be more accurate. The velocity thus obtained in feet per second, multiplied by the area of the flue in square feet, gives the number of cubic feet of air discharged per second. The extracting power of a flue does not increase directly with its height, owing to the friction and the cooling of the air as it ascends.

### (2.) Air-currents caused by mechanical means.

**Mechanical Systems** o ventilation can be divided into two classes: the sucking-out or "vacuum," and the blowing-in or "plenum."

In the "**vacuum**" system, although the inlets are not completely under control, no draughts will be experienced if they are properly arranged so that the in-flowing air is sufficiently diffused. The fresh air can be, of course, warmed when necessary by passing over heated pipes or radiators.

* See Buchan's "Ventilation" (1891), page 140.

In the "**plenum**" **system**, the fresh-air inlets are always under control. It requires, however, that all the windows in the building should be kept shut, but this is not a very great hardship in a noisy smoky city.

Mr. Nesbit, in his lecture to heating engineers in April, 1898, stated "that to obtain the same purity, quantity, regularity, etc., of air-supply and allowing for convenience of working, the extra cost of the 'plenum' system over the 'vacuum' is a very moderate amount. As far as the actual apparatus is concerned, it has been found, from estimating certain buildings, that the 'plenum' system costs less than a radiator scheme on the same efficiency basis, but the extra cost of builder's work more than compensates for this difference."

Under some circumstances, the most successful results are obtained by a combination of extraction and propulsion.

The disadvantages of **mechanical ventilation** are principally cost of instalment and working, and risk of temporary cessation due to the machinery breaking down; while the advantages are the large volume of air that can be dealt with, and the command that can be obtained over the fresh air admitted.

The **motion of the air** may be brought about by fans, pumps, jets, etc., actuated by steam, oil or gas engines, electric motors, or even water power.

The **fans** used in this country, for ventilating purposes, are composed of a number of rotating metal blades of various shapes. There are two distinct forms: the "enclosed" or "centrifugal," and the "facial" or "axial." In the former case air is forced in a direction at right angles to the axis of the fan, and in the latter in a direction more or less parallel to the axis. The centrifugal variety are usually called "blowers" and "exhausters," while the axial ones are called "open

fans" or "air-propellers." The efficiency of a fan is reckoned by the volume, velocity and pressure of the induced air-current obtained by the expenditure of a definite number of H.P.'s. When air at a high velocity and pressure is required, blowers are employed, but an open air-propeller is more suitable to use for obtaining a large volume of air at a low velocity and pressure.

The **enclosure** in which the fan rotates is concentric with it when high pressure is required, and of a spiral form for a large volume at low pressure and velocity. The outlet is generally horizontal and at the top or bottom, while the air enters the casing through an aperture in the side.

For ventilating draught-closets, etc., in chemical laboratories, blowers should be used, as they are more efficient and reliable than axial fans; a little more power is necessary, but the trunks can be smaller, generally of about a quarter the area

In the makers' catalogues, the amount of air that any particular fan or blower will move in a given time is usually calculated in free air; in actual practice, however, there is resistance offered by the trunks, heating-pipes, etc., to the movement of the air, hence an addition of from 10 to 50 per cent. should be made. To resist the action of chemical fumes, the blades should be coated with acid-resisting paint or be formed of tinned copper; the bearing of the shaft can be usually kept outside the trunk, and the shaft can run in oil. Air must have very free access to a facial fan. Each variety of fan has a definite velocity, beyond which the ratio between the power expended and the increase of volume and pressure obtained becomes greater and greater. Although small ones can be, with advantage, run faster than larger ones, it is more economical to use a large fan at a low velocity than a small one at a high

velocity, but the resistance offered by the ducts, etc., may necessitate a high pressure to force air through them.

The **force** required to drive air through a flue at a definite velocity is obtained by multiplying the total amount of internal surface in the flue by the square of the velocity, and again by the co-efficient of friction (generally taken at about 0·03).

**Pumps** are more satisfactory than fans in one particular only, the quantity of air dealt with is accurately known. They are large, heavy, comparatively slow in action and wasteful of motive power.

**Jets** of steam, water or compressed air are seldom used; they are, like pumps, extravagant and often have the additional disadvantage of being somewhat noisy.

The various **motive powers** for driving the fans, etc., have already been given, viz., steam, oil, and gas engines, electric motors, and water power.

The power required to run a fan varies approximately with the cube of the speed. The selection of the motive power is generally influenced to a great extent by the source of power utilised for warming and other purposes. When considerable power is required for the ventilation, a **steam engine** is advisable, otherwise a **gas engine** will be, very likely, found more convenient, but the ease with which a couple of wires carrying electric current can be run, even to distant or inaccessible parts of a building, render an **electric motor** an excellent arrangement. As sufficient water is seldom available without heavy expenditure, **water power** is almost invariably quite out of the question, although an hydraulic motor is very convenient, as it can be placed where desired, with merely supply and waste pipes connected to it.

The fresh air that is drawn into the building should be as pure and clean as possible, therefore the intake should be about 10 or 15 ft. above the ground; if it is at the roof level, not only will the duct probably be objectionably long, but the air is liable to be contaminated with smoke. Sometimes the air after entering the building passes through a water spray and is thereby cleansed, moistened and, in summer, cooled. Instead of using merely a water spray, screens of various materials, such as jute and cocoa-nut fibre, or iron baffle plates, may be employed to remove the dust particles from the incoming air. If water is allowed to intermittently flow down these screens, it cleanses them and at the same time moistens the air passing through. The objection to such screens is in the resistance they offer to the air-current and the increased motive power thereby necessitated. The temperature of the fresh air is usually raised by passing it over pipes heated by water or steam. On a large scale, it is a convenience to have one or more mixing chambers, in which the warmed air can be diluted with colder fresh air to bring the temperature down to that considered most suitable for the various rooms, corridors, etc. This propulsion and treatment of the fresh air generally requires considerable basement-space; therefore to avoid considerable outlay, the system adopted may be either mechanical air-extraction, or else natural ventilation where full advantage is taken of the means employed for warming and lighting the building.

The system of ducts must be planned and proportioned with great care; partial or even total failure may result through neglecting to take into account the resistance offered to the passage of air through them due to friction against the sides, or to changes in their direction or size. Numerous inspection openings

should be provided for removing any dust and dirt that, by accumulating in the ducts, may cause unnecessary friction, and also render the air passing through less suitable for respiration. In new buildings, the ducts should be, where possible, formed in the thickness of the walls and floors. To reduce the friction as much as possible, the perimeter of the cross-section of the ducts should be kept small compared with the area, and the internal surfaces should be smooth. Hence circular glazed stoneware pipes, or cement-rendered flues with rounded angles are best. Glazed bricks or tiles are, of course, preferable but very expensive. If the ducts are on the surface of the walls, they are least obtrusive if made of galvanised steel or wood; if the latter material is used, it must be well-seasoned and smooth inside.

The following scheme for ventilating a **chemical laboratory** was given in a paper read before the American Society of Heating and Ventilating Engineers in January, 1898.* This paper was prepared by the late Mr. Frank Ashwell and revised by Mr. D. M. Nesbit:—

"On no account whatever is connection permitted between the extraction from the chemical department and the general extraction from the rest of the school.

"The great aim in designing the extraction from this department is to prevent the possibility of smell and fumes getting into the other departments of the school.

"The following plan has proved perfectly satisfactory. At a convenient position in the roof-space a chamber of brick or wood, well tarred, is formed. A fan, say 24 in. to 30 in. in diameter, according to the

* See "Heating and Ventilation" (New York), for January 15th, 1898.

amount of air and fumes to be extracted, is fixed with a vertical or horizontal shaft, as is most convenient structurally, the air extracted by the fan being blown into the outer air through a dormer or tower. The fan is, as far as possible, constructed of copper and driven by an electric motor placed outside the chamber on the suction-side. The means of starting and stopping the fan is operated from the room of the head of the chemical department. All extraction flues from the chemical department are carried into the fan chamber above mentioned. The areas of the openings from the chemical rooms are in excess of the areas of the inlet flues from the plenum system, so that by proportioning the flues this way, there will be a slight pull into the room when a door is opened, which would not be the case without the fan and if the extraction flues were of equal area. A good rule is to proportion the extraction flues through the draught-closets and tables so that their combined area will equal the combined area of the inlet flues from the plenum, and to provide, besides, extraction flues in the walls whose combined area is equal to half the area of the inlet flues. Thus, in the event of some of the draught-closets being closed, an increase of extraction area over inlet will still be maintained. In the chemical department it is wise to arrange for the ordinary extraction (as in the cases of other departments) for top and bottom extraction and, besides, fit each extraction opening with a shutter to regulate or wholly close it if desired. If one large extraction flue can be arranged to take the benches, draught-closets, and deal with the ordinary ventilation as well, an excellent result is obtained, a direct opening into the flue from the top and bottom of the room being made, which should be fitted with a valve for regulation. As it is necessary to run flues from the tables,

which are in the centre of the room, the floor is made deep enough to take a main extraction trunk formed of a glazed earthenware trough covered with glass, into which the small flues from the tables and draught-closets run at an angle in the direction of the air-current; this main trunk may be graduated according to the number and size of flues taken into it. Its area, however, due to being horizontal, is in excess of the sum of all the small flues. In some cases it is convenient, instead of running this main trunk under the floor and up the wall in one vertical flue, to divide it into two or more, one down each side of the room and running up the wall in two flues. These vertical flues are of earthenware, the square section used being more convenient for constructional purposes than a round one. The vertical flues on reaching the roof are carried into the fan chamber before mentioned, care being taken that the areas are not reduced at any point. The ordinary extraction from the room is taken up directly to the roof and connected to the fan chamber."

## WARMING.

The **warming** of a building may be either local or central.

**Local** heating is done by the aid of fireplaces or stoves in each room.

**Central** heating is carried out by means of a furnace or stove in the lowest part of a building, the heat being conveyed to the various rooms by water, steam or air, circulating in pipes, or by naturally-rising or artificially-forced air.

Heat is transmitted by conduction, convection or radiation, but for all practical purposes it can be

considered that the temperature of air can be raised only by contact with hot bodies.

**In open fireplaces** (modern patterns) about 30 per cent. of the heat due to the combustion of the fuel is lost up the chimney; they, however, warm almost exclusively by radiant heat, which is the pleasantest and most healthy variety. Most of the modern forms of grates have fireclay backs and sides, which retain a large amount of heat, and so increase the radiation. To obtain the maximum amount of heat out of the fuel, and the most complete combustion, the volatile gases in the coal must be set free and burnt at a high temperature. Ordinary fireplaces, as already mentioned, act as valuable ventilating agents. Warm-air grates, however, are in this respect far superior, because a supply of external air is brought into a chamber constructed behind the back and sides of the grate, and, after being warmed, is delivered into the room through an opening between the mantel-shelf and the ceiling. This warm air takes the place of that extracted by the fire, and thus the amount of space warmed is doubled, but the first cost of the grate is somewhat greater (page 124).

**Stoves** warm principally by the air coming into contact with heated surfaces, which, however, must not be overheated, or an unpleasant dryness and smell will result. Slow-combustion stoves should have fireclay linings; they may be, like grates, of the warm-air (ventilating) type. In a stove without an air-warming arrangement, a somewhat larger proportion of heat due to the combustion of the fuel is generally made use of than in an ordinary grate. If the stove is placed in the centre of the room, the smoke-flue is generally first taken down, and then horizontally under the floor, and

*lastly vertically upwards; the vertical portion should be at least three times the length of the horizontal and* descending portion; the level part must admit of sweeping, and be surrounded by non-combustible material, as, for example, stoneware pipes bedded in concrete.

Open fireplaces and stoves are only suitable for small rooms; they require constant attention, and are liable to cause inconvenience from smoke, dust and ashes.

**Gas fires** are especially valuable on account of their entire freedom from these disadvantages. If the rate of consumption of gas is properly attended to, the result obtained is more uniform than with a coal or coke fire. Some prejudice still exists against them, but it is founded on erroneous ideas, and due largely to the dangerous practice, not altogether infrequent, of using them without proper flue-pipes having gas-tight joints. In order to obtain as much radiant heat as possible, the stoves should have "atmospheric" burners, and asbestos or ball fuel. It is generally best to have a gas fire of greater power than is normally required, in order to be able to warm the room rapidly before it is occupied, and also in case of unusually severe weather. Care has to be taken, however, that unnecessary waste of gas does not take place. Condensing stoves should be only used in very exceptional cases, such as when extra heat is required during severe weather; only the water and sulphur compounds are condensed, but some of the carbonic acid can be absorbed by means of frequently-renewed potash solution.

Mr. Thos. Fletcher, F.C.S., of Warrington, has made a number of comparative tests with gas fires,* measuring the radiant heat with a black bulb thermometer

* "Coal Gas as a Fuel," supplement to 5th edition.

*in vacuo*, and taking the best gas consumption for the fire tested when at full power.

| *Pattern of Fire.* | *Gas consumption per hour.* | *Rise of thermometer 3 ft. from fire-surface.* |
|---|---|---|
| Asbestos fibre ... | ... 27 c. feet ... | ... 41 degrees. |
| Ball fire ... | ... 26 ,, ... | ... 41 ,, |
| Iron spray ... | ... 23 ,, ... | ... 54 ,, |

From these figures he calculated the cost, for an equal amount of radiant heat, with:—

| | |
|---|---|
| Asbestos fibre | = 153s 3*d*. |
| Ball fire | = 149s 8*d* |
| Iron spray | = 100s 0*d* |

With the same fires turned down low, the results were:—

| | | |
|---|---|---|
| Asbestos fibre ... | ... 8 c. feet ... | ... 15½ degrees. |
| Ball fire ... | ... 8 ,, ... | ... 8 ,, |
| Iron spray ... | ... 8 ,, ... | ... 16 ,, |

With ball fires, the fuel in front prevents a large proportion of the heat being radiated out into the room; in fact, not less than ⅘ths of the heat are lost up the flue.

If these fires had had an air-warming arrangement, that is, if the convected heat had been fully utilised, the total duty would have been the same in all cases.

The consumption of 1 c. ft. of 18 candle-power coal-gas will raise the temperature of 2,460 c. ft. of air 20 degrees Fahr., if the heat is fully utilised.

The cost of using gas fires works out at fully three times that of coal fires. At London prices, the cost of the fires per unit of heat is about five times as much for gas as it is for coal.

Where coal or gas fires are used for warming chemical laboratories, and gas-burners for the ventilation of the draught-closets, any ether or other highly-inflammable heavy vapour that has been allowed to escape,

will be naturally drawn by the air-currents towards the flues, and so these "naked lights" constitute a "risk" that is not incurred when low-pressure hot-water pipes and fans are used.

**Hot-water Pipes** are either on the low-pressure or open system, or else on the high-pressure or closed system.

**Low-pressure Pipes** are of cast and wrought iron, varying from 6 in. to 1 in. in diameter, according to the length of the runs and the work to be done. They are heated by a boiler in the basement to any temperature not exceeding 190° or 200° Fahr. Coils or radiators are placed in the system where additional heat is required; the former are horizontal pipes connected at the ends, and the latter are vertical pipes connected at the top and bottom. The pipes warm by the air coming into contact with the heated surface, but when heated to a high temperature the proportion of radiant heat is very perceptibly increased. With this system the temperature can be easily regulated and evenly maintained, but if worked intermittently, there is a risk of the water freezing in the pipes when they are not in use.

**High-pressure Pipes** are generally of wrought-iron and $\frac{7}{8}$ in. internal diameter, heated to 300° Fahr. or more by a furnace, in which about $\frac{1}{10}$th of the total length of piping is coiled. As in the low-pressure system, the water circulates through flow and return pipes, but the expansion pipe here is not open to the air, and so no steam is generated. The temperature of the pipes varies at different parts, and rises and falls very quickly with the condition of the fire; there is a considerable risk of overheating the pipes and setting fire to anything easily inflammable that may be close to them. The chief advantage over the low-pressure

system is in the pipes, which are small and therefore economical of space and easily adapted to various situations.

**Steam** is particularly suitable for use where the warmth is required at great distances from the source of heat, or where there are variations in the floor-levels. Its use is greatly on the increase in this country. With properly-arranged steam-pipes there is no danger from freezing, and this cannot be said for hot-water pipes, but there is perhaps more tendency to overheat the rooms.

Steam-pipes are of all sizes, according to the length of the mains and the distance from the work. Both, however, steam and high-pressure hot-water pipes, are frequently too small.

The high-pressure steam system is not much used for heating purposes.

The low-pressure gravity system, when properly arranged, is satisfactory for schools, etc.

In vacuum steam heating, the air is pumped out of the pipes, into which the steam is admitted at atmospheric pressure or lower. The advantages of this system over high- and low-pressure steam heating are the comparatively low temperature obtainable, the absence of air-valves, and the easier passage of the steam, from which heat is obtained more quickly and in slightly greater amount. As low a temperature as 175° Fahr. can be obtained.

If exhaust steam is used, an oil separator is necessary.

Either "exhaust" or "live" steam, or both, can be used.

Steam is very convenient for intermittent use.

Unless exhaust steam is available, this mode of heating is not often employed, as a boiler is needed for

supplying the steam, and this necessitates skilled supervision.

Neither hot-water or steam pipes should be placed in a channel below the floor-level if it can be avoided, as dust will accumulate and cannot be removed; besides, the amount of heat wasted is considerable.

**Ventilating radiators** connected to hot-water or steam pipes were referred to under "Ventilation" (page 125); the fresh-air inlet on the inside face of the wall should be capable of being closed at night. If the radiator is enclosed, the outlet for the warmed air should be along the top of the front of the case, and should be adjustable; sometimes valves are fitted to allow the hot air before it leaves the casing being mixed with fresh air that has not passed over the radiator. The external surface of radiators should be as plain as possible, so that they may be readily kept free from dust.

**Warm air** can be used for raising the temperature of rooms in various ways. The method of warming fresh air by means of grates, stoves, and ventilating radiators has been already described (page 135); there is also the basement furnace, which warms air, and either delivers it by means of ducts into the various rooms, or causes it to circulate through a series of pipes. In some buildings there is merely a stove or heater in the basement, and the warmed air is allowed to circulate naturally up through the various rooms by means of the staircases and corridors. Warm-air systems are not altogether satisfactory, as air at a sufficiently high temperature to properly warm walls, etc., in cold weather is very objectionable. In relative cost of installation and fuel hot air is the least expensive,

then high-pressure hot-water, followed by low-pressure hot-water; and lastly, steam. Repairs, however, cost very little in low-pressure hot-water, but are very expensive in high-pressure hot-water.

**Warming by electricity** is at present too expensive for general use.

**School Buildings**, if not very extensive, can be satisfactorily warmed by hot-water pipes with radiators or coils, supplemented by warm-air grates for use when additional heat is required. It is usually considered that from 8 ft. to 10 ft. run of 4-in. pipes are required for every 1,000 c. ft. of air in the room to be warmed if the desired temperature is between 55° and 58° Fahr., and the thermometer outside is near freezing-point. An extra two or three feet are necessary if the ventilation is particularly good. The boiler generally has 1 sq. ft. of heating-surface for every 35 ft. run of 4-in. pipes.

A physical laboratory can be warmed without the introduction of iron, on a small scale, by means of brick grates, preferably fitted with air-warming arrangements, or on a large scale by adopting the plenum system (see page 127). Stoves and pipes of glazed ware are bulky and costly, and take a good deal of warming-up at starting; they have, however, the advantage of retaining heat for a considerable period of time.

In the recent Parliamentary Report on the Ventilation of Workshops, already referred to, the Committee consider the heating arrangements should be capable of maintaining, if necessary, a temperature at least 15 degrees Fahr. above that of the outside air, in the absence of lights and persons.

Every heating engineer has his own method of calculating **the amount of heat required** in a particular building to keep the temperature up to a given standard, and it is only possible here to indicate the basis usually adopted.

English engineers almost invariably adopt the methods of Professor Eugene Péclet, of Paris (as given in Thos. Box's "Practical Treatise on Heat," 1900). Several of Péclet's co-efficients have been confirmed recently by Lees, Christiansen, etc.

In this country the temperature required to be reached and maintained is generally taken at 60° Fahr., for class-rooms, and 55° for corridors, assuming the temperature of the outside air to be 32° Fahr.

The heating apparatus must be powerful enough to raise the walls and air of the room to the given temperature, and to maintain them at that temperature.

**The total amount of heat** required to raise the air of a room to a given temperature, and keep it at that temperature, is the amount of heat absorbed and lost by the walls, windows, floor, and ceiling, *plus* that necessary to warm the air supplied for ventilation, *minus* the heat given off by the persons and lights in the room.

Heat is lost through the walls, etc., by conduction, radiation, and contact with cold air.

These amounts of heat can be calculated in pounds—Fahr. units, in the following manner:—

(1) **The amount of heat absorbed** by the walls before the required internal temperature is reached is found by multiplying the total weight of the walls, in pounds, by the specific heat of the material of the walls, and again by the difference between the required mean temperature of the mass of the walls and the outside air temperature. The weight of a cubic foot of

brickwork is 112 lbs. and its specific heat 0·19. This may be expressed as an equation:—

$$H_1 = W \times s \times (t_1 - T_1).$$

While this heating of the walls is going on they are losing heat to the external air and objects, but the average amount lost per hour is less during the heating-up than after the desired internal temperature has been reached.

(2) **The amount of heat lost** by the walls per hour, after the required internal temperature is reached, is found by multiplying the total area of wall-surface, in square feet, by the difference between the required temperature and the outside air temperature, and again by a constant:—

$$H_2 = S \times (T - T_1) \times c.$$

**The amount of heat dissipated** by the windows is ascertained in a similar manner.

This constant for the walls depends on the material and thickness. According to Professor R. C. Carpenter, of Cornell University, author of "Heating and Ventilating Buildings," Péclet's constants, reduced to English measures, are: For a brick or stone wall, 12 in. thick = 0·32, and 20 in. thick = 0·26, while for an ordinary window, the constant varies from 0·91 to 0·98 (according to height).*

The corresponding co-efficients adopted by the German Government, and given by Alfred R. Wolff, M.E., in a lecture at the Franklin Institute, are 0·32, 0·23, and 1·09 respectively. These agree closely with the figures given in Kinealy's "Formulas and Tables for Heating," on pages 36—38. Engineers generally make a varying, but usually considerable, allowance for movement in the outside air.

* From "Domestic Engineering" for March, 1897, page 28.

Again, some authorities add an extra 10 per cent. for northerly aspects, and an extra 20 per cent. for very exposed situations.

In England, heat-losses through floors, ceilings, and internal walls are, in most cases, neglected.

Professor Carpenter gives* a simple formula—

$$h = \left(\frac{n}{55} C + G + \frac{W}{4}\right) t.$$

Where $h$ = total number of heat-units required per hour,
$n$ = number of times air of room is changed per hour,
C = cubic contents of room in cubic feet,
G = total area of window-surface in square feet,
W = total area of exposed wall-surface in square feet,
and $t$ = number of degrees Fahr. difference between room-temperature and external temperature.

He has taken the heat-loss per hour per degree Fahr. difference between room-temperature and outside temperature for every square foot of surface, at one unit for glass and at ¼ unit for external walls. He has also reckoned that one heat-unit will warm 55 c. ft. of air 1 degree Fahr.

(3) **The amount of heat** necessary per hour to warm the air supplied for ventilation, is found by multiplying the weight, in pounds, of the total quantity of air admitted per hour, by its specific heat, and again by the number of degrees its temperature has to be raised. The total quantity of air admitted per hour is taken as the allowance per head per hour, multiplied by the number of persons the room is intended to accommodate. The weight of a cubic foot of air is 0·078 lbs., and the specific heat of air is 0·238.

$$H_3 = w \times s^1 \times (T - t).$$

The cooling effects of the air which is continuously diffusing into the room through the wall-surfaces, crevices in the windows, doors, etc., are usually neglected.

* "Heating and Ventilating Buildings" (1901), page 59.

(4) **The amount of heat** given off per hour by a man at ordinary room-temperatures and available for heating purposes is about 190 units.*

$$H_4 = N \times 190.$$

An ordinary gas-jet gives off as much heat as four men.

Having estimated, by this method, the maximum number of heat-units required per hour, the correct amount of hot-water or steam piping can be determined, if the heating-power of the various descriptions of pipes is shown. For example, a square foot of heating-surface on a 4-in. pipe at 160° Fahr. will give out 175 heat-units per hour, if the air is at 60° Fahr.; if steam at about 200° Fahr. is employed instead of hot-water, the number of units should be increased from 175 to 280.

## ARTIFICIAL LIGHTING.

**Artificial light** is obtained by means of oil, electricity, coal-gas, acetylene and other gases. The lights can be frequently arranged so that they assist the ventilation of the room in which they are placed.

In a **chemical laboratory** the principal illumination is generally derived from lights on the benches, but there are usually a few larger lights or groups of lights suspended from the ceiling or roof. If it can be managed, it is preferable to provide a separate light on a branch situated over each working-place, or, at any rate, one light to each pair of working-places. In the latter case, however, care must be taken that there are no shadows

* Box's "Heat" (1900), page 242; but Kinealy, in his "Formulas for Heating" (1899), page 11, quotes Pettenkofer, Rubner, and Barrel as giving for adults about 400 heat-units!

cast on the benches from the reagent-shelves or other fittings.

In a **lecture room** the lighting must be arranged to allow the students to take notes on dark days, or in the evening, and also, if possible, during the projection of pictures on the lantern-screen. Unless the lecture-table is quite short, a series of distributed lights above it is preferable to one or more groups. The illumination of the black-board must not be forgotten.

The suspension of oil lamps of the ordinary pattern from the ceiling of a room is unsatisfactory, chiefly on account of the large shadow cast by the reservoirs; this disadvantage, however, does not exist in the inverted "regenerative" form. The problem of applying incandescent mantles to oil lamps for general purposes has not yet been quite satisfactorily solved.

The use of incandescent mantles, for burners supplied with **coal-gas**, is now becoming very general, owing to the great increase of candle-power thereby obtained, and the economy in gas-consumption. The usual form of mantle is an upright one, but an inverted one can be now obtained. The mantles of the "Inverted Incandescent Gas-lamp Syndicate" are extra strong and require no chimney or mantle-stick; all shadow is avoided, which is a very great gain. When coal-gas is the source of light, it is advisable to have a suitable "governor" on the main pipe or at each "point," to prevent the pressure rising above the desired amount. Their cost is soon got back in the smaller amount of gas burnt, and for many fittings, such as the Wenham, Siemens, or incandescent-mantle burner, a uniformly steady pressure is essential. Especially where there is no governor, the illuminating power of an ordinary Bray's burner can be very appreciably increased, without altering the rate of consumption of

the gas, by slipping over it a suitable "economiser"; the gas then issues at a reduced pressure; the flame is, however, very sensitive and ragged.

**Electric light** has many advantages over other forms of illumination, one of the most important being that it does not vitiate the air and gives out comparatively little heat. For large rooms with flat ceilings, "naked" arc lights or Nernst lamps, with inverted conical reflectors below, afford a very pleasant diffused light, reflected from the ceiling.

COST OF PRODUCING 1,000 CANDLES OF LIGHT DURING ONE HOUR,* without allowing for maintenance, repairs, etc.:—

16 candle-power **coal-gas**, at 3*s*. per 1,000 c. ft.

| | |
|---|---|
| Flat-flame burner, 13 c.p., 5 ft. per hour | = 13·8 pence. |
| Welsbach mantle, (say) 60 c.p, 3·5 ft. per hour | = 2·1 ,, |

**Electricity**, at 4*d*. per Board of Trade Unit.

| | |
|---|---|
| Arc lamp, 450 c.p., 250 watts | = 2·2 pence. |
| Nernst lamp, 65 c.p., 100 watts | = 6·2 ,, |
| Incandescent electric lamp, 16 c.p., 50 watts | = 12·5 ,, |

**Petroleum.**

| | |
|---|---|
| Kitson's incandescent oil lamp, 1,000 c.p. | = 0·8 pence. |

COMPARATIVE COST OF VARIOUS LIGHTS PER HOUR,* irrespective of their relative intensity:—

| | |
|---|---|
| Flat-flame burner, 13 c.p., 5 ft. per hour | = 0·18 pence. |
| Welsbach mantle, (say) 60 c.p., 3·5 ft. per hour | = 0·13 ,, |
| Arc lamp, 450 c.p. | = 1·00 ,, |
| Nernst lamp, 65 c.p. | = 0·40 ,, |
| Incandescent electric lamp, 16 c.p. | = 0·20 ,, |
| Kitson's incandescent oil lamp, 1,000 c.p. | = 0·80 ,, |

* From "Public Lighting by Gas and Electricity," by W. Dibdin, F.I.C., F.C.S. (1902), page 425.

*Acetylene has been successfully used for several years in various schools about the country, where coal-gas is either unobtainable or too expensive. As for safety, when the installation is carried out by certain firms, the insurance companies do not require any increase in the premium on existing fire-policies.*

Each pound of carbide should yield about 5 c. ft. of the gas, which should be led through a purifier to rid it of phosphuretted and sulphuretted hydrogen, etc. Care should be taken to have the generator large enough for the requirements. For lighting purposes, the pressure is only about 3 in. of water, but, if it is also used for heating, a pressure of from 6 to 7 in. is required. An ordinary 20 candle-power burner consumes from $\frac{1}{3}$ to $\frac{1}{2}$ c. ft. of acetylene per hour, while a Bunsen burns about 1 c. ft. per hour. Many special laboratory fittings, such as burners for foot-blowpipes, combustion and muffle furnaces, evaporation-closets and for use in the lantern, are now procurable. Notwithstanding the great heat of the flame, the fracture of glass vessels is, with ordinary care, scarcely greater than with coal-gas.

# APPENDIX A.

## BOARD OF EDUCATION.

**Article 85 (a)** of the code provides as follows :—

"All new school premises and enlargements must be approved by the Board before such new premises and enlargements are passed under this article."

RULES TO BE OBSERVED IN PLANNING AND FITTING-UP SCHOOLS.

### Public Elementary Schools.

**Rule 18 (d).** *Science Room.*—A room suitably fitted for elementary practical work in Science may be provided for the use of one large or several contributory schools. Such a Science room should not, as a rule, contain more than 600 sq. ft. of floor-space. It should be fitted with strong and plain tables, sinks, cupboards, and shelves, and where necessary, a fume closet. A proper supply of gas is necessary.

In addition to a Science room, one of the ordinary class-rooms may be fitted with a simple demonstration-table and gas and water supply. But a special lecture-room cannot be approved in an ordinary public elementary school.

### Public (Higher) Elementary Schools.

**Rule 19 (b).**—Every Higher Elementary School should be provided with suitable laboratories.

(i) The laboratory accommodation must be sufficient to provide at one time for the largest class in the school.

(ii) There should generally be one laboratory for chemistry and one for physics.

(iii) A laboratory should afford 30 sq. ft. of floor-space for each scholar, the minimum size will therefore be 600 sq. ft., but it is as a rule desirable that the laboratory should be somewhat larger. If, however, the laboratory accommodates more than twenty-five scholars a second teacher would be required.

(iv) Laboratories may be fitted with suitable tables, which must be well lighted; they should be properly supplied with gas and water. For chemical laboratories, sinks, cupboards and the necessary fume closets must be provided.

(v) A small balance room may be provided if desired.

(c) (i) In addition to the class-rooms and laboratories a Higher Elementary School may include a lecture-room, which should be fitted with (1) a demonstration-table furnished with a gas and water supply and a sink, and (2) a fume closet. A lecture-room should have an area of about 750 sq. ft.

(ii) If no separate lecture room is provided, each of the class-rooms used by the third and fourth years should be fitted with a simple demonstration-table.

(iii) A small preparation room, fitted with bench, sink, cupboard and shelves, and proper supply of gas, should be provided in a convenient position.

# APPENDIX B.

## BOARD OF EDUCATION.

### SUGGESTED LABORATORY ARRANGEMENTS FOR PRACTICAL WORK IN CHEMISTRY, METALLURGY AND PHYSICS.

(From the Supplementary Regulations for Secondary Day and Evening Schools, 1st August, 1902, to 31st July, 1903.)

### LABORATORY FOR PRACTICAL INORGANIC CHEMISTRY.

Where payments are to be claimed in Practical Chemistry the school must be provided with a laboratory which has been passed by the Inspector as satisfactory.

The laboratory must be properly fitted and equipped and meet all sanitary requirements, and will be expected to comply generally with the following conditions. Each student should have a working-space of at least 3 ft. 6 in. by 2 ft. 3 in. on the bench-table. Shelves for reagents, etc., should be fitted above, and drawers and cupboards for apparatus, etc., below the table. Gas should be laid on to each student's bench, and there should be a water-tap with an earthenware or lead-lined sink for every two students, if possible. Closets should be provided for evaporation of substances evolving noxious fumes and for sulphuretted hydrogen work. These closets should be ventilated by flues carried up in the wall of the building, so as to ensure the extraction of the fumes. Niches with flues should also be provided for combustion furnaces.

The laboratory and apparatus must be kept clean, tidy, and in good order—failing which payment may be reduced

or withheld. It must be set apart entirely for the study of Practical Chemistry; it may not be used as a class-room for any other subjects.

Each bench must be furnished with sufficient apparatus and be always kept in good working order.

### Laboratory for Practical Organic Chemistry.

A laboratory fitted up and passed by the Inspector for Practical Inorganic Chemistry may be also used for instruction in Practical Organic Chemistry, provided that the appliances commonly employed in organic analysis and investigation are kept for general use in the laboratory.

### Laboratory for Practical Metallurgy.

In most cases comparatively small additions to the Chemical Laboratories, arranged and furnished in accordance with the prescribed regulations for Practical Inorganic Chemistry, will enable Practical Metallurgy to be taught.

It is necessary that one or more wind furnaces should be provided, and these furnaces should be in connection with a flue at least 30 ft. high. The furnaces may be placed in a basement below the laboratory, but there is no objection, if space permits, to one being in the laboratory.

There must also be a muffle furnace capable of heating to bright redness a muffle at least 8 in. long, 4 in. wide, and 3 in. high; when there is an abundant supply of gas, gas muffle furnaces may be adopted with advantage.

No more than three candidates will be allowed to use the same muffle furnace at any examination in Practical Metallurgy.

The muffle furnace may be in the laboratory, as it is also useful in conducting various chemical operations.

Each student should be provided with the tools and appliances set forth in List I., and those named in List II. must be kept in the laboratory for the use of the students.

List III. gives the reagents, fluxes, etc., that will be required by the students for general use.

## List I.

Each student in the Advanced Stage and Honours must be provided with the following articles. In the Elementary Stage the student need only have the articles that are marked with an asterisk:—

*1 small hammer.
1 small anvil.
1 drill.
*1 steel spatula.
*1 camel-hair brush.
*1 hard tooth brush.
2 sheets of glazed paper.
*1 pair of scissors.
1 pair of pliers—half round, taper.
1 pair brass forceps.
*1 triangular file.
*1 wire triangle—covered.
2 glass rods.
1 glass funnel, 3 in. diameter.
4 beakers, Nos. 5, 6, 7 and 8.
*1 washing bottle, fitted.
2 conical flasks and small funnels.
2 Bohemian flasks, 24 oz.
1 Berlin evaporating dish, No. 7.
1 do. No. 2, 3½ in. diameter.
*1 porcelain mortar.
*1 porcelain crucible, 1½ in. diameter.
1 packet of filters, 6½ in. diameter, or filtering paper
6 test tubes.
2 ft. combustion tubing.
1 lens.
*6 scorifiers, 2½ in. diameter.
12 cupels.
*6 earthen crucibles, each size, 1¾, 2½, and 3 in. diameters.
*1 black lead crucible, 3 in. diameter.
*2 roasting dishes, 3 in. diameter.
*1 duster or cloth.

*1 notebook.
½ oz. silver, or old or foreign silver coin.
2 dwts. gold, or old or foreign gold coin.

## List II.

The following must be kept for general use :—

3 pairs of furnace tongs.
1 open ingot mould.
1 ingot mould with hemispherical cavities.
1 copper scoop.
1 cupel mould.
1 mould for making small clay crucibles.
2 iron cupel trays.
1 iron mortar.
1 anvil, 4 in. by 4 in.
1 hammer.
1 pair of metal shears.
1 pair of flatting rolls.
1 bucking plate and iron.

## List III.

The following metals and reagents, which need not be of a high degree of purity, must be kept in addition to the ordinary stock of a chemical laboratory :—

Antimony.
Arsenic.
Bismuth.
Copper.
Iron (hoop and wire).
Lead (in thin sheet free from silver).
Mercury.
Tin.
Zinc.
Charcoal.
Sulphur.
Antimony Sulphide (black).
Bismuth Oxide.
Copper Oxide (black).
Copper Sulphate.
Cobalt Oxide.
Iron Oxide.
Litharge.
Red Lead.
Lead Sulphate.
Manganese Oxide (black).
Mercury Sulphide (red).
Nickel Oxide.
Tin Oxide.
Zinc Oxide.
China Clay.
Glass, Powdered.
Lime.
Salt.
Fireclay.
Silicious Sand.
Fluorspar.
Red Argol.
Borax.
Dry Sodium Carbonate.

## Suggested Laboratory Arrangements for Practical Work in Physics.

The laboratory should be a well-lighted room, fairly lofty and with adequate ventilation. It should be situated preferably on the lowest floor of the building, in order to secure freedom from vibration. There should be sufficient space between the benches to allow of easy passage.

The lighting might conveniently be from two adjacent sides of the room, leaving abundant wall-space for blackboard, diagrams, cupboard-space, and certain experiments with pendulums, levers, etc., needing blank wall.

Arrangements should be made for providing a dark room for photometric or other measurements requiring artificial illumination. This may be done either by fitting dark blinds to the windows of the laboratory or by screening off a portion of the darker side of the room with thick baize curtains.

The working-benches recommended should be in the nature of plain strongly framed tables, about 2 ft. 9 in. high, placed as far as possible in the middle of the room, and stone benches built into two side walls or wooden ones strongly fastened. The tops of the benches should be of hard well-seasoned wood and unpolished. The benches should be suitably equipped for the experiments to be performed on them—a permanent place should be assigned to apparatus whose accuracy may be impaired by moving it. A mercury table is a useful adjunct.

Gas should be laid on to each bench.

An over-head rail for suspension, fitted with hooks and clamps, is a useful addition to at least some of the benches.

At least two large sinks with water supply and waste should be provided in a laboratory for twenty students.

It will be necessary to provide considerable cupboard-space, also lockers, both for the sets of apparatus supplied to each student, and for apparatus to be distributed when required.

The apparatus supplied to each student must vary in

accordance with the nature of the practical course. It is not expedient to place too much apparatus in the student's hands in the first instance; the bulk of what is needed should be reserved for special distribution.

## BOARD OF EDUCATION.

### LISTS OF APPARATUS SUITABLE FOR USE IN SCIENCE CLASSES.

### Inorganic Chemistry.

For the purposes of lecture demonstration a sufficien supply of glass and other apparatus, including diagrams, required for illustrating the subjects enumerated in the several syllabuses must be provided.

For experimental work to be done in the laboratory by the students each working-place should be furnished according to the following list:—

Conical brass blowpipe, with bone mouthpiece.
Platinum wire, 6 in.
Platinum foil, 2 in. long, 1 in. wide.
Test tube stand, 12 holes and 12 pegs.
Test tubes, 30 of 6 in. by ¾ in.
Test tubes, 12 of 5 in. by ½ in.
Conical flasks, 2, 8 oz., with wide necks, for use with filter pump.
Test tube brushes, 2.
Beakers, a set of 5, 4 oz. to 16 oz.
German flasks, 1 each—2 oz., 4 oz.; 2 each—8 oz. and 16 oz.
India-rubber stoppers with 2 holes to fit each of the two largest flasks.
Royal Berlin porcelain crucibles, 1¼ in. and 1½ in.
Best German porcelain evaporating basins, 1 each—2¾ in., 3½ in. and 4 in.
Funnels, 2 of 2½ in., 1 of 2 in.
Funnel holder for two funnels.

Filtering paper, 1 packet each 7 c.m., 9 c.m. and 11 c.m. diameter.

Two iron tripod stands, 8 in. high, one round, one triangular.

Iron retort stand, 20 in., with three rings and clamp.

Iron gauze, 5 in. square, 2 pieces, with asbestos interwoven.

Sand bath, 5 in., tin-plate.

Watch glasses, 2 in., 6.

Desiccator.

Glass tubes, soft, $\frac{3}{16}$ to $\frac{1}{4}$ in. diameter, $\frac{1}{2}$ lb., in lengths of about 2 ft.

Thin glass rods, $\frac{1}{8}$ to $\frac{3}{16}$ in. diameter, $\frac{1}{4}$ lb., in lengths of about 2 ft.

Black caoutchouc tube, $\frac{3}{16}$ in. bore, 4 ft.

Black caoutchouc tube, $\frac{1}{8}$ in. bore, 2 ft.

Corks, 2 doz., assorted.

Triangular file, 5 in., in handle.

Round file, 5 in., in handle.

Pair of scissors.

Bunsen's gas-burners, 2, with regulators for gas and air, with blowpipe, jet, star support, chimney and rose.

Bowed crucible tongs, brass, 7 in.

Composition mortar, 4 in.

Cobalt blue glass, 4 pieces, $1\frac{1}{2}$ in. square.

Cork borers, set of three.

Two horn spatulas, 3 in. and 4 in.

Three test paper rolls, 1 red, 2 blue litmus.

Two dusters.

Drying cone.

Two pipe triangles.

Two weighing bottles.

Three clock glasses.

Balances, weights, thermometers, burettes and other graduated vessels, electric current, with means of regulating and measuring the current used in electrolytic experiments, and a stock of reagents must be supplied for general use.

## Applied Mechanics.

All experimenting must be done by the students themselves. Models to be merely looked at are of little value.

Models or actual specimens of the more important mechanisms used in transmitting power; there ought, if possible, to be means for measuring velocity, ratio and efficiency of transmission of power.

Models or actual specimens of lifting machines, such as screw and hydraulic jacks, cranes, pulley blocks, Weston pulley block, inclined plane, etc., arranged so that their efficiencies may be measured under very different kinds of loading. Waste of energy in using a simple pulley; in the rolling of the wheel of a bicycle, in the hub of a cycle with roller bearings.

Quantitive illustrations of the triangle and polygon of forces; principle of moments; the lever; friction between solids with and without lubrication, friction in fluids; forces in parts of a hinged structure; centrifugal force; friction between a belt and a pulley; the balancing of rotating things.

Transmitting and absorbing dynamometers; efficiency of a motor worked by water; efficiency of an electric motor.

Attwood's machine; apparatus to show the relation between kinetic energy and speed of a fly-wheel; momentum before and after impact of two bodies; to illustrate rule as to time of vibration of a body, and the stilling of vibrations by fluid friction; the laws of forced vibrations.

Surfaces of metals, timber and other materials arranged for examination by magnifying glasses or microscopes.

Apparatus enabling the stiffness of springs to be measured.

Simple apparatus for comparing stress and strain in material till it is broken; in tension, compression, shearing, twisting, bending.

Apparatus to measure rise of pressure due to more or less sudden stoppage of water flow in a pipe.

Models of a centrifugal pump, of a jet pump, and of a turbine, to be taken to pieces and drawn by students. Measurement of flow of water from orifices and over gauge notches. Model allowing pressures to be measured at various points along a pipe of varying section; to measure force due to a flowing jet of water.

There must be good means for making measurements of length and weight of objects usual in workshops or laboratories.

A planimeter ought to be in use by some student during every lesson. Squared paper must constantly be in use in finding the relation between quantities measured in the experiments. Much of the time usually spent in lecturing to students ought to be given up to the experimenting of the students themselves. Any of the laboratory apparatus may be exhibited on the lecture-table. A heavy ball hanging by a steel wire from the ceiling illustrates many things; beams and shafts of india-rubber are useful to a lecturer.

## Sound, Light and Heat.

Instructions by which the teacher can, at little expense, set up pieces of apparatus for himself, are given in the "Outline of Experiments and Description of Apparatus and Material," suitable for illustrating elementary instruction in this subject, published by the Board of Education and obtainable from Messrs. Eyre & Spottiswoode, London, price 6*d*.

### Elementary Stage.

#### Sound.

Monochord with two strings, one with pulley to carry weights. Set of weights, 1 lb. to 14 lb. Tuning key.

Brass and steel piano wire of various thicknesses.

Pair of flat-nosed pliers.

Two or three tuning forks, the larger the better, with resonance boxes; violin bow.

Apparatus to show wave lines traced on smoked glass.

Round rods of wood, 5 or 6 ft. long, and about $\frac{3}{4}$ in. diameter.

Rosin, flexible leather, soft wax, bristles.

Thin board of pine. Long thin wooden lath.

Vice or clamp for fixing rods and vibrating bodies to the table.

Knitting needles, bright steel rod, twisted steel spring, bright silvered beads.

Row of marbles in a groove, or solitaire board.

Long spiral spring of wire supported horizontally by threads attached to a frame.

Long caoutchouc tube, with ring for attaching to ceiling or wall.

Two tinned-iron tubes about 3 ft. long, with supports.

Simple form of Savart's wheel and siren, or a top mounted with toothed wheel and perforated disc.

Air-pump, receiver, and bell, to show effect of rarefied air on sound.

LIGHT.

Lantern and screen (or large sheet of cardboard).

Cap to lantern with slit.

Grease-spot and shadow photometers.

Pin-hole camera.

Pieces of plane silvered glass (plate, or patent plate).

Apparatus to illustrate laws of reflection, preferably for use with lantern.

Apparatus to illustrate laws of refraction, preferably for use with lantern.

Two inclined mirrors, mounted on board with divided circle. Concave and convex spherical mirrors on stands.

Set of lenses of various forms, convex and concave, with holder; 60° prism of glass; 60° prism of bisulphide of carbon; two glass wedges; total reflection prism.

A piece of thick plate-glass, or a glass slab.

Batswing burner on stand, with flexible tube (where gas supply is available); wax candles, cardboard, etc.

Glass cell to hold liquids.

## Heat.

Glass beakers (1 doz. assorted); glass flasks (three or four of 4 oz. capacity, several larger); glass tubing (about 1 lb. of quill tubing, a few lengths of larger size, and of alcohol thermometer tubing); one or two small glass funnels.

Mercury; methylated spirit and aniline to colour it; salt, nitre, sulphate of soda, etc. A supply of ice should be arranged for.

Bunsen-burner and flexible tube, or large spirit lamp.

Retort stand, with rings and clamp. Iron tripod stand. Sand bath. Pneumatic trough, or stoneware basin.

Two thermometers, chemical form, $-10^\circ$ to $110^\circ$ C.

Hypsometer. [Barometer.]

Compound metal bar to show effect of unequal expansion.

Ball and ring, or rod and gauge, to show linear expansion.

Apparatus to illustrate method of measuring expansion of a solid rod.

Apparatus to illustrate method of measuring absolute expansion of liquids.

Apparatus to show maximum density of water.

Differential air thermometer. Simple form of air thermometer.

Balance on stand, with set of brass weights, 500 grm. to 0·1 grm.

Calorimeter of thin brass or copper. Some open tin cans.

Small cylinders of various materials, all of equal size (wood, cork, glass, lead, iron, brass, copper, etc.).

Pieces of lead about ½ lb. or 1 lb., cast in blocks, with hook attached.

Block of iron of 1 lb. weight, with hook attached.

Copper ball, with hook.

Tin can fitted with cork and delivery tube for experiments on latent heat. [Air pump and receiver to show water boiling under reduced pressure.]

Cryophorus.

Ether and pair of bellows, to show cold produced by evaporation.

Glass apparatus fitted to show convection currents.

Cylinder, half of wood, half of brass, to illustrate conduction of heat.

Rods of iron and copper joined together at one end to illustrate unequal conductivity.

### SOUND.—ADVANCED STAGE.

Apparatus consisting of bent tube and mercury to illustrate Boyle's law.

Models to illustrate amplitude, wave length, phase, etc.

Set of tuning forks on resonance boxes; two in unison, one an octave higher, as many others as possible. One or two should be mounted with mirrors attached to the prongs.

Large concave reflectors on stands.

Siren and bellows with windbox.

Set of organ pipes; one with manometric capsules.

Clamp and set of plates for Chladni's figures.

Wide glass tubes and cylinders for resonance experiments.

Galton's whistle.

Apparatus for producing a sensitive flame.

Melde's apparatus for showing vibrations of strings.

Apparatus for showing Kundt's dust figures; lycopodium powder.

### LIGHT.—ADVANCED STAGE.

Goniometer and sextant, or models of them.

Optical bench, graduated, with sliding holders for lenses, mirrors, etc.

Achromatic pair of prisms; ditto lenses; 60° prism of carbon bisulphide.

Semicircular strip of polished metal or silvered glass to show "caustics."

Spectrometer, for measuring refractive indices and showing spectra.

Simple form of telescope. Opera glass.

Glass V-trough, with divisions to illustrate refractive indices of liquids.

Apparatus to show Newton's rings.

Rings of wire and soap solution to produce soap films.

Finest wire gauze to show effects of diffraction.

Photographic or other cheap diffraction grating.

Piece of Iceland spar. Nicol's prism. Pile of glass plates.

Polariscope. [Saccharometer.]

Newton's colour disc and means of spinning it. Coloured glasses, papers and solutions.

Wool test for colour blindness.

Tube of phosphorescent powder. Phosphorescent paint.

Fluorescent liquids (eosin, sulphate of quinine, fluorescein, etc.).

Chemicals and photographic sensitive materials to show chemical action of light.

## HEAT.—ADVANCED STAGE.

Maximum and minimum thermometers.

Apparatus to illustrate measurement of increase of volume of air at constant pressure.

Apparatus to illustrate measurement of increase of pressure of air at constant volume.

Calorimetric apparatus.

Apparatus to show development of heat by friction.

Black bulb thermometer *in vacuo*.

[Bunsen's ice calorimeter.]

Apparatus to show vapour tension of different liquids (barometer tubes, mercury and trough, with support for the tubes).

Hygrometer. Wet and dry bulb thermometers.

Leslie's cube. Thermopile, and astatic galvanometer.

Thermo-electric couple of bismuth and antimony.

M 2

Thermo-electric couples of iron, nickel and copper.

Fire syringe.

Simple apparatus to illustrate the principle of Clement and Desormes' experiment.

[Apparatus for the determination of the mechanical equivalent of heat.]

## Magnetism and Electricity.

### Elementary Stage.

Piece of loadstone, with stirrup for suspending it.

Pair of bar magnets with keepers.

Horseshoe-magnet with keeper.

Pieces of soft iron bar, and of steel bar.

Steel knitting needles; clock-spring steel; soft iron wire.

Iron filings, with muslin bag for sifting them.

Iron nails. Hoop-iron.

Frame from which to suspend magnets, etc.

Cocoon silk for suspensions.

Balanced magnetic needle on pivot. Compass needle.

Poker. Hammer.

Rods of glass, smooth and roughened. Rods of vulcanite, shellac, sulphur, sealing-wax. Rubbers of silk, flannel and fur.

White silk ribbon and floss silk. Cotton thread. Fine iron and copper wire (bare).

Gold-leaf electroscope. Proof planes. Metal trays.

Condenser for the electroscope.

Brass tube, insulated, with glass or vulcanite handle.

Insulating supports. (Cakes of paraffin wax will serve.)

Insulated conductors of various forms, including two insulated metal balls of equal size.

Electrophorus.

Leyden jars: One with movable coatings, discharge tongs.

Butterfly net.

Hollow conductors for showing Faraday's "ice-pail" experiments.

Induction electrical machine.

Iron wire gauze, for screening effects. Brass chain.

Variable condenser (roll of tin-foil on insulating rod).

Differential condenser with movable plates. Slabs of glass, paraffin, sulphur, etc., for use with it.

Plates of varnished glass. Sheets of thin vulcanite or caoutchouc.

Tin-foil. Covered copper wire (1 lb. of Nos. 24, 30 and 16).

Simple voltaic cells (examples of the common forms). Battery of three or four cells, capable of sending a fairly strong current.

Pieces of sheet zinc and copper. Plates of carbon.

Binding screws and clamps.

Commercial nitric and sulphuric acids. Mercury, copper sulphate, sodium sulphate, litmus, acetate of lead, etc.

A few yards of bare German silver wire and bare iron wire.

A simple astatic galvanometer.

Thin iron, platinum, and silver wires to show differences of conductivity.

Apparatus for the electrolysis of water.

Flat coil of wire and solenoid mounted on corks, with zinc and copper plates, to float on acidulated water.

Right and left-handed helices. Electromagnet.

ADVANCED STAGE.

Dip needle.

Magnetometer.

Induction coil. Vacuum tubes to show chief features of the discharge in rarefied gases.

Mirror galvanometer.

Tangent galvanometer.

Wheatstone's bridge (metre form).
(Post Office form).

Apparatus to show the mutual attraction and repulsion of conductors carrying currents of electricity.

Barlow's wheels.

Apparatus to show the laws of induced currents.

Resistance coils.

## Theoretical Mechanics.—Solids.

### Elementary Stage.

Balance and weights, metre-sticks (to show the difference between "end-measure" and "line-measure," one stick a metre long and another showing the engraved lines 1 metre apart as in the actual standard), graduated measuring jar, burette.

Model vernier.

Small geometrical solids of different materials for estimation of lengths, areas, volumes, densities.

*Hare's apparatus and U-tube for equilibrium of two different liquids.

*Specific gravity bottle.

Spring balance, spiral spring, and a dynamometer (india-rubber).

Means of demonstrating the parallelogram of forces.

Hicks's ballistic balance.

Apparatus to show the acceleration of bodies falling *in vacuo*.

Simple pendulum, compound pendulum.

Attwood's machine.

Inclined plane (hinged so as to be capable of adjustment).

Levers, model of common steelyard, single pulleys, and a pair of compound pulley-blocks having three pulleys in each block.

Wheel and axle, wedge, screw, spherometer, screw gauge and sliding callipers.

Apparatus to show resistance to (1) elongation, (2) compression, (3) bending, (4) torsion. Apparatus for study of moments, etc.

### Advanced Stage.

Any school which has an advanced class should possess all the apparatus mentioned under the elementary stage, and should also have blocks of different material (wood, metal, leather, etc.) for demonstrating the laws of friction

and for measuring the co-efficient and angle of friction with the aid of the adjustable inclined plane.

* Model to show how indicator diagrams are obtained.

## Theoretical Mechanics.—Fluids.

### ELEMENTARY STAGE.

Apparatus marked * in list for Mechanics of Solids, and—

Flask with side tube.

Hydrometers (Nicholson's, etc.).

Glass cylinder open at both ends, with brass supports at one end and a movable base for demonstrating variation of pressure with depth of a liquid.

Apparatus to show equilibrium of liquid in communicating vessels.

Pascal's vases or their equivalent.

Apparatus to demonstrate the principles of flotation and stable and unstable equilibrium (rods, blocks, etc.).

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Barometer tube, mercury basin, scale.

Bourdon's metallic barometer to show principle of steam gauge.

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### ADVANCED STAGE.

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Regnault's hygrometer.

Apparatus for demonstrating capillary phenomena.

# APPENDIX C.

## A SIMPLE METHOD OF FORMING ASBESTOS FLUES.

**Asbestos** withstands the action of fumes, chemicals and heat, but is softened by water. Hence, it is a suitable and durable material to use inside a building for flues which carry off fumes and heated air and are not exposed to any quantity of moisture.

An asbestos "slate" is manufactured which is dense, hard and waterproof. As this, however, cannot be moulded to any required shape, it is better to use a cheap quality of mill-board, about ⅛ in. thick.

The flue should have the fewest possible joints, and all fastenings or other metal should be on the outside only.

When fixed on the face of a wall, a flue U-shaped in section is less conspicuous than a circular or square one.

To avoid unnecessary friction, the internal surface should be smooth and as free from angles as possible.

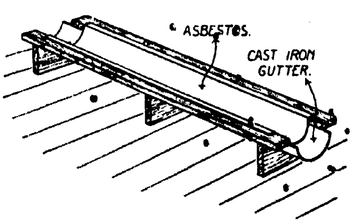


FIG. 35.—METHOD OF MOULDING THE MILL-BOARD.

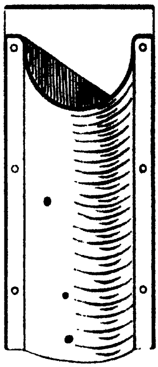
**Figure 35** shows a simple method of moulding an asbestos flue, the only requisites being a length of cast-iron rain-water gutter and some pieces of wood.

The sheets of mill-board are usually about 40 in. square; they can be readily cut into strips of the required width

with an ordinary knife, and a few minutes soaking in water renders them quite pliable.

It is advisable the inside of the gutter should have a coat of paint before being used, to prevent rust forming.

First, the flat strip is temporarily tacked to the wall and then the curved strip, which has side flanges about 1 in. wide, is nailed on, preferably with copper nails. The flanges should be damp when they are being fixed, in order to obtain an air-tight joint; the nails must be driven into either a board or wood-plugs, plaster alone does not give them sufficient hold. The adjacent ends of the moulded strips can be butted together and the joint covered with a narrow piece of the damp mill-board.



SKETCH OF FLUE.

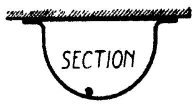



FIG. 36.

Asbestos that has been soaked in water takes a good many hours to dry, but when it has lost all the moisture it can be cut or sawn, like wood.

If wished, it can be distempered or painted to correspond with the wall.

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THE END.

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